A CASE STUDY OF EVALUATING THE IMPACT OF COST OF QUALITY FOR CIVIL ENGINEERING DESIGN SERVICES IN A SMALL CORPORATION

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ABSTRACT

This case study evaluated the cost of quality (CoQ) for Civil Engineering Design Services (CEDS) in an Alaska based firm. The firm currently lacks a mature Quality Management System (QMS), which is needed to control and measure CoQ. As a means to justify the implementation of a QMS Feigenbaum quality costs were captured from historical job data and used to develop a Juran and Gryna Optimum Quality Cost Model. During the model development non-parametric testing was performed to determine the following; does the overall job budget size have an effect on quality cost, is there a correlation between appraisal and failure cost, and is the firms CoQ performing at an optimum level as defined by the quality models constructed. The non-parametric testing indicated that budget size did not have an effect on CoQ, appraisal cost are related to failure cost, and the firms CoQ was not optimized in its current state. The firms CoQ, per job, without an active QMS was determined to be 8.9% of the job cost with failure cost accounting for 5.2% of the total cost. By implementing a QMS such as ISO 9001 the firms CoQ, per job, is predicted to reduce to 6.1% of the job cost. This reduction could be achieved by increasing appraisal cost to 4.5% of the total budget, which is predicted to decrease the failure rate to 0.5% of total job cost.

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LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviation	Name
ASCE	American Society of Civil Engineers``
ASQC	American Society for Quality Control
CEDS	Civil Engineering Design Services
CoQ	Cost of Quality
DNR	do not reject
FY	Fiscal year
ISO	International Organization of Standards
L	large
M	medium
NSW	New South Wales
S	small
QMS	Quality Management System

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CHAPTER 1 - INTRODUCTION

This case study was performed to provide an analytical approach to evaluating the Cost of Quality (CoQ) in a civil engineering design firm which currently lacks a mature Quality Management System (QMS). The CoQ modeling selected as a starting point for the case study was the Feigenbaum (1956) and Juran and Gryna (1974) quality models. These models provided a simplified CoQ system which could be integrated with the very basic data available to the author.

The case study was performed using data available through the firms accounting software and the author's knowledge of the systems and work processes within the firm. The author is a senior manager with the firm and a licensed professional civil engineer in the State of Alaska.

1.1 THE FIRM AND WORK TYPE

The Firm, as it shall be referred to through the remainder of the report, is a small corporation licensed in the State of Alaska. The Firm was established in 1994 and has been in continuous operation since that time. The Firm consists of a multidisciplinary staff including engineers, scientists, planners, drafters, and other support staff. The workload of the Firm consists of planning, permitting, design, and construction management services. The design work may be further separated into civil, environmental, mechanical, and structural design services. The Firm is considered a "Small Enterprise" with a full time staff of less than 50 employees and annual revenues of less than $11 Million (Centre for Strategy & Evaluation Services, 2012).

This case study focuses on one service line within the Firm, the Civil Engineering Design Services (CEDS). CEDS typically involves products whose end result is used by the general public. These products may include airports, bridges, buildings, dams, levees, roads, storm sewer system, sanitary sewer systems, water systems, and others. Within the CEDS workload product development, submittals may vary from preliminary planning documents to the full design packages ready for construction.

The research for this case study focuses on a specific type of product developed by the CEDS. This product includes design packages used to construct public facilities within Alaska. The facilities specific to this case study include roads and bridges. A design package is a set of construction documents developed by the CEDS team. These documents typical consist of design reports, plan, and specification which a contractor uses to construct a facility.

1.2 DEFINITIONS

During the course of the author's research, it became clear that there is a need to provide consistent terminology definitions used throughout this project. There are some words, or phrases, used in this project which have meanings that are altered from the conventional definitions. These alterations were done out of necessity in order to accurately describe what was occurring in the case study. Definitions which have been altered from the conventional meaning are denoted with an asterisk (*) adjacent to the word.

1.2.1 GENERAL DEFINITIONS

Quality Management System: A performance-reporting system and it is defined as a formal system of accumulating and reporting data useful for the achievement of management's objectives. (Mauch, 2010)

Job: Refers to an individual CEDS project that was included in the population sample.

Job Size: Describe the size of a job based on the overall project budget.

Firm: The Corporation which this case study focuses on.

Design Package: A set of construction documents that typically consist of design reports, plans, and specifications which a contractor uses to construct the facility.

1.2.2 CoQ Definitions

Tangible Cost: Quality costs which are measurable (Juran, 1951).

Intangible Cost: Quality cost which are not measurable, or difficult to measure, such as loss of reputation, lost opportunities, or loss of business (Juran, 1951).

Prevention Cost*: Cost to prevent poor quality from occurring. (Feigenbaum, 1956)

Appraisal Cost*: The cost of reviewing design packages prior to releasing the final product to the client/owner.

Failure Cost*: The cost of correcting errors in the design package which were brought to the Firms attention during construction activities. These costs do not include costs incurred by the contractor or owner as a result of the error.

CoQ: The sum the prevention, appraisal, and failure cost.

1.3 DESCRIPTION OF RESEARCH

This case study evaluated an Alaska based CEDS corporation to reduce the Firms CoQ. The firm currently lacks a mature QMS which is needed to control and measure CoQ. As a means to justify the implementation of a QMS Feigenbaum quality costs were captured from historical job data and used to develop a Juran and Gryna Optimum Quality Cost Model.

During the model development non-parametric testing was performed to determine the following; does the overall job budget size have an effect on quality cost, is there a correlation between appraisal and failure cost, and is the firms CoQ performing at an optimum level as defined by the quality models constructed.

This report will outline the literature review, methodology, results, and managerial decisions w completed during the case study.

CHAPTER 2 - LITERATURE REVIEW

2.1 INTRODUCTION

The manufacturing sector has used quality management as a framework for monitoring and evaluating quality processes since the 1920's according to, The History of Quality Management (2015). In the 1950's a type of managerial accounting was developed which evaluated the cost of product quality throughout the products lifecycle. This system allowed managers to make informed decisions about the production of a product, from a quality standpoint, and make adjustments to process as need to improve profits. Today the quality movement is booming with annual quality spending nearing $3 Billion dollars in the United States (Sloma-Willams, 2004)

Quality movements are generally developed to accommodate the manufacturing industry where widgets are produced in the billions and there is a distinct need to monitor and control processes. The quality movements of manufacturing are not as easily replicated in the engineering design services arena as a business does not mass produce products, the products are individually developed. The uniqueness of each engineering design job makes it difficult to apply a "cookie cutter" approach to measuring quality, and quality cost in a meaningful way. This is not to say that it cannot be done, but there does not appear to be a standardized, or regularly accepted, approach that engineering design consultants are gravitating towards.

2.2 COST OF QUALITY

The first discussion of CoQ began in 1949 with the American Society for Quality Control (ASQC) and C.W. Kennedy's article "The Gold Mine in Quality" in the *Purchasing Journal*. In this article Kennedy discussed many techniques still used today such as production inspections, sampling, and control charting. He also outlined how the improved quality could lead to reductions in cost, improvements in sales, and the reduction in staffing which ultimately would lead to greater profits.

The first detailed outline of CoQ was developed by Juran in 1951 the first edition of his *Quality Control Handbook*. This book laid the framework for CoQ in that it began to define costs directly associated with quality. Juran separated quality cost into two categories: tangible and intangible. Tangible were all quality cost that could be measured. These included inspection, testing, and losses related to errors. He also was the first to define intangible cost. These are cost that may include loss of business, customers, reputation, or opportunities.

In 1954, Lesser of the General Electric Company developed strategy for justifying his quality management budget. He evaluated four main cost categories: direct materials, direct overhead, labor, and engineering. He needed a way to describe and identify quality cost to the management in a way that could be easily interpreted. To do this he suggested that the cost be normalized against a base such as net sales or direct materials. With this approach the framework for the managerial accounting movement using CoQ was born.

Realizing that Lesser's approach was limited to a single department another General Electric Company employee Armand Feigenbaum (1956) proposed a new way to think about quality that would encompass the entire product lifecycle from its inception through the shipment to the customer. In this approach he outlined the seven stages of an industrial cycle in which all needed to play a role in the quality of the product.

In 1963, the Department of Defense entered into the quality movement with their release of MIL-Q-9858A: *Quality Program Requirements*. This document required that all defense contracts for products and services use these guidelines for quality management purposes.

The ASQC, in 1967, established the Quality Cost Committee which began to publish guidelines on quality cost which helped to standardize the CoQ movement.

The CoQ movement continued on and is still a very competitive and advancing field. For the purpose of this research we end our journey here as this case study looks at the very core principles of CoQ.

2.3 COST OF QUALITY MODELS

Quality costs were first defined by Juran in 1951 with tangible and intangible cost. In 1956, Feigenbaum defined the tangible cost in form that is now known as the basic PAF model (Loduca, 2011). The PAF model consists of three basic cost components: prevention, appraisal, and failure. The sum of these cost are defined as the CoQ. In 1960, Freeman further refined the failure cost into two components: internal and external.

Juran and Gryna (1974) are credited with first defining the most economical level of quality as shown in Figure 1. This quality model uses the Feigenbaum PAF model to define quality costs which are then graphed to reveal the optimum quality level. This is now considered the classical view of CoQ. The modern view of optimized CoQ presented by Juran and Gryna (1988) shows that optimum conformance is at zero defects. This modern model is shown as Figure 2.

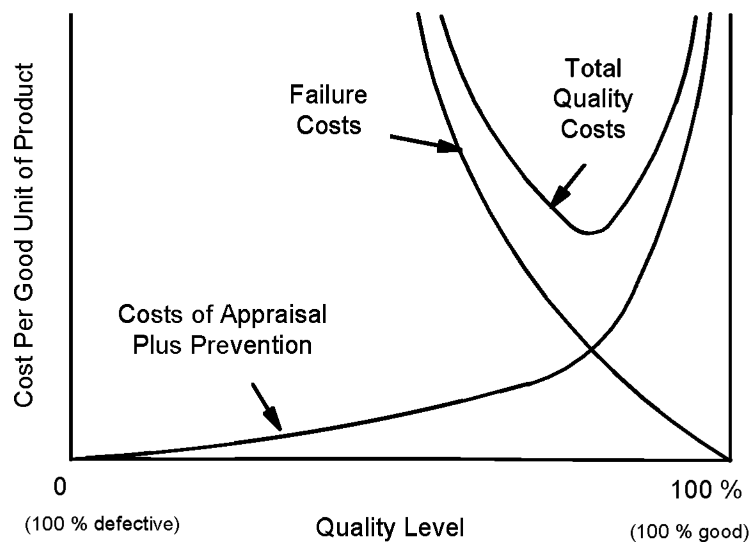

Figure 1 – Classical View of CoQ (Juran and Gryna 1974)

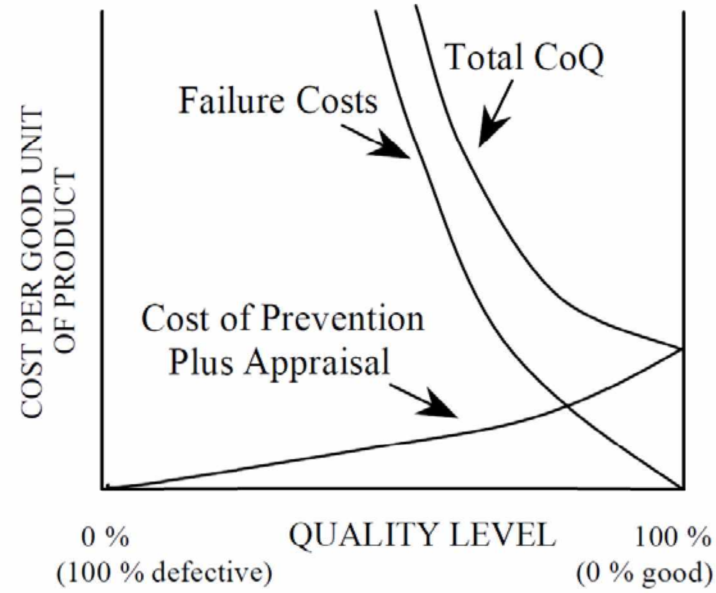

Figure 2 – Modern View of CoQ (Juran and Gryna 1988)

2.4 THE QUALITY MANAGEMENT SYSTEM

In order to evaluate the CoQ of a process there needs to be a system in place for controlling and measuring those processes. This function is best served by a QMS. By the QMS we are referring to very generic system for which there is a formal method for collecting and reporting useful data that will allow an organizations management effectively make decision about performance (Mauch, 2010).

The QMS can be defined, or established, within organizations in many ways. Since the quality revolution began in the 1940's with the Japanese rebuilding their factories after World War II, industry's focus on quality has driven the growth from abroad to industries within America (Rokke & Yadav, 2012). In this growth of quality throughout industry, particularly in the manufacturing sectors, there are a number of initiatives, or methods, which have been established and to guide organizations in their incorporation of quality into their processes.

As earlier stated CEDS is difficult to measure, or fit, into a standard QMS system as it lacks some of the repletion that the more popular QMS's use for the measurement and control of quality. However, there have been some standardized systems that may be gaining traction in the CEDS quality movement.

2.4.1 QMS in Civil Engineering Design Services

In 1987 the International Organization for Standardization (ISO) published the first version of ISO 9001. This is a quality management standard that applies to manufacturing, processing, legal services, financial services, banking, retailing, drilling, aerospace, construction, exploration, textiles, pharmaceuticals, oil and gas, pulp and paper, publishing, petrochemicals, shipping, mining, energy, telecommunications, plastics, metals, research, health care, hospitality, utilities, aviation, machine tools, agriculture, government, education, recreation, tourism, fabrication, sanitation, software development, consumer products, transportation, instrumentation, computing, biotechnology, chemicals, consulting, insurance, and others (A Brief History on ISO 9001, 2015). The most current version of ISO 9001 2015 was released in 2015 which combines and replaces all previous versions of the ISO 9000 series into one standard.

While ISO 9001 was not directly developed for CEDS there is research that indicates that it may be the most applicable commercialized QMS available to the public. Neikerk (2011) demonstrated that the implementation of the ISO 9001 system within the CEDS was possible with great results. It was suggested that a quality manual consisting of an introduction, policies, procedures and standard documentation, developed in accordance with the requirements ISO 9001 could have great return by reducing errors and improving quality conformance by 84%.

In 2012, Botha performed a case study evaluation of CEDS firms that incorporated ISO 9001 as basis for their QMS. Botha demonstrated two key points in his work. First, that a QMS was only successful if the employees using the program had confidence in its results. Second, that the implementation of the QMS by the firm had the potential to reduce the extent of professional indemnity cases against the firm. Although the results of the second point were inconclusive, the results were encouraging in that the answer was not a definite “no”.

By nature engineers and engineering firms are reluctant to change, especially if there is no mandate by a client, professional standard, or government body to require such. In August 2013 CEDS in New South Wales (NSW), Australia got a big push by the Government of NSW. In the report, *Quality Management Systems Guidelines* issued by the Government, all services providers for government products were highly encouraged to initiate quality activities by implementing ISO 9001 within their QMS. This international push was echoed in the United States with the America Society of Civil Engineers (ASCE) approval and endorsement of the ISO 9001 system for use in CEDS (ASCE 2014).

2.4.2 THE NEED FOR QMS

The need for a standardized QMS system in CEDS is not a new thing. Sanderson & Ricketts (1988) urges the Institution of Civil Engineers to initiate QMS citing the need to maintain a quality level expected of their construction counterparts. In 1993, Hamzah performed a case study of construction failure and found that 40-50% of the failures were due to faulty designs, or errors in plans and specifications. Love and Heng (2000) performed a study similar to Hamzah and found similar results concluding that 51% of failure during construction could be traced back to the project's design package.

Habrecht (1994) an engineer with the AVCA Corporation published *Quality Management in an Engineering Firm Environment* where he detailed the need for a standardized QMS. Habrecht stated that if anything, the QMS system could bring additional profits to the company be reducing overhead which he related directly to errors or mistakes on design packages.

In the development of a model to implement a lean QMS system in a design engineering firm Marzouk et al., (2012) indicated that the management of engineering design is most neglected area in construction process. Williams (2013) made a similar statement indicating that the lack of engineering design management was major contributor to failure within case study of 47 individual construction failures.

2.4.3 The Benefits of QMS

We have demonstrated a need for QMS in the CEDS now what is the benefits. Nothing is worth changing if there is not a reward or benefit for making the change. Davis et al. (1989) found that 47% of design time is quality based. With the implementation of a QMS a firm would be better able to track these activities and look for improvements.

Loduca (2011) indicates Total CoQ, in engineering design, ranges from 45-65% of total revenues without a mature QMS. This was not directly measured from CEDS but it was hypothesized that engineering design services followed the software design in their quality model. If this value is accurate then the implementation of a QMS and the reduction CoQ could be very beneficial to the engineering firm's bottom line.

It is important to note that errors or mistakes on design packages often effect more than the engineering design firm. These errors can cost both the owners and the contractors building the projects substantial amounts of money. Cnuddle (1991) found that design errors failures account for 4.6% - 9.2% of total project cost in construction. Burati et al. (1992) found something very similar, that design errors/failures account for 9.5% of total project cost.

In all the above examples there was one common theme, money. Anytime there is an error or mistake in a design package someone has to pay for it. Be it the engineering firm, the owner, or the contractor. Often times it's hard for owners and contractors to look the other way when the loss of money can be directly linked to the services provided by the engineering firm.

CHAPTER 3 - RESEARCH OBJECTIVES

Prior sections of this report have demonstrated the need for, and the benefits of, monitoring the CoQ and having a mature QMS. This case study will evaluate the Firm's CoQ to determine if there is a cost benefit to placing effort into maturing the Firm's QMS.

To evaluate the CoQ for the Firm the author collected data from jobs with a wide range in overall budgets. In order to determine if this data is appropriate to be used together, the job size was tested for size effect. This led to the first research objective.

1. Evaluate if job size has an effect on CoQ, i.e. size effect.

Another question that needed to be answered, or understood, was if there was a link between appraisal cost and failure cost. Both appraisal and failure cost were uniquely defined for this case study. See Section 1.2.1 for their definitions. Intuitively, one would think that as appraisal cost increased the failure cost would decrease. So this led to the second research objective.

2. Evaluate if there is a correlation between appraisal and failure cost.

In order to understand the Firm's current CoQ a basis was needed to evaluate the status. The Feigenbaum PAF model was chosen as it represented a very simplistic but accepted method for quantifying cost. The third research objective is as follows:

3. Evaluate the firms current CoQ, based on Feigenbaum's PAF model using historical data and descriptive statistics.

In order evaluate if the Firm's CoQ was optimized the Feigenbaum PAF model developed as objective 3 was integrated with the modern view model of optimized quality cost developed by Juran and Gryna.

4. Use the data collected in the Feigenbaum's PAF Model; develop a CoQ model outlining an optimized system which minimizes CoQ as defined by Juran and Gryna.

Using the combination data collected and models developed in objectives 3 and 4, it is necessary to understand if the Firm's existing CoQ was operating at its best and by proxy if the QMS requires improvements.

5. Evaluate if Firm's current CoQ is optimized based on the Juran and Gryna model.

The sixth and final objective was to evaluate all the information as a whole and make managerial decisions about how the Firm should interpret the result of this case study and what should be done, if anything, to improve the CoQ and QMS.

6. Evaluate the quantitative data and provide managerial recommendations based on observations.

CHAPTER 4 - METHODOLOGY

4.1 INTRODUCTION

In order to meet the objectives, outlined in Section 3, the methodology of the case study was broken into five distinct parts as outlined the Methodology Flow Chart, Figure 3. This methodology section will provide the details in how data was collected, processed, and analyzed. It will also demonstrate model development and the optimization process.

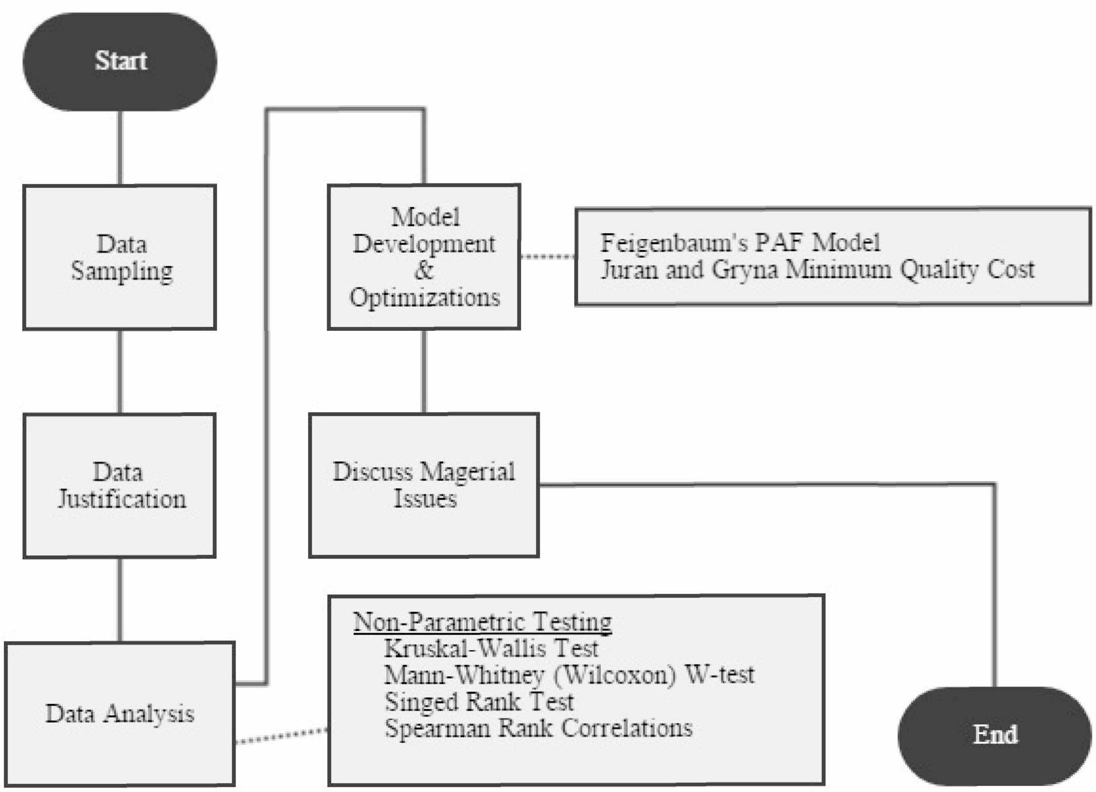

Figure 3 – Methodology Flow Chart

4.2 DATA SAMPLING

The first step in understanding the Firm's CoQ was to evaluate the historical workload of the Firm. This was done by reviewing archive project data contained in electronic file system and in some cases reviewing paper, or hard copy, files. Although the Firm has been in business for over 20 years the author choose to only evaluate projects from fiscal year (FY) 2009 to FY2015. The decision was made primarily on the availably of data. The firm underwent a financial software change in FY2008, records from FY2008 and older are difficult to access. In addition, prior to FY2008 the Firm's use of electronic filing of project data was in its infancy so much of the available project data is in hard copy format only. The Firm's fiscal year runs from May to April.

4.2.1 POPULATION

The Firms workload, as discussed in Section 1.1, consists of a variety of jobs from planning documents through design and construction management activities. Table 1 shows the historical job information collected from the Firm for FY2009 through FY 2015.

The data presented in Table 1 represents the population being evaluated as part of this project. The population its self consists of individual jobs. These jobs have been separated into three distinct categories: All Jobs, Design Jobs, and Design Jobs Constructed.

<u>All Jobs</u>: Represent the total number of jobs completed by the Firm that year. As the name implies these include all jobs with no categorization based on type of job.

<u>Design Jobs:</u> These are jobs that the end result is a construction ready design package which has the potential of being constructed by an owner or contractor. All jobs within this category have undergone some level of quality review. Most design packages are signed by a professional engineer, whom operates under a standard of care. According to Ashcraft (2002) the standard of care for engineering design is not infallible,

but reasonable care and competence at a level of the other engineers practicing in the same profession.

Design Jobs Constructed: These jobs represent designs developed by the Firm that were later constructed in the public sector by private contractors or other entities.

Table 1 – Historical Job Data

Historical Job Data			
Year	**All Jobs**	**Design Jobs**	**Design Jobs Constructed**
2009	66	24	9
2010	35	18	7
2011	29	7	3
2012	56	16	11
2013	53	11	4
2014	70	23	8
2015	30	9	4
Count	**339**	**108**	**46**
μ	**48**	**15**	**7**

4.2.2 Sampling Method

All sampling for this case study was subjective. Section 4.2.3 describes how the data was selected and why the data sampling was not random.

4.2.3 Population Sample

The jobs of interest for this case study consist wholly of design jobs that have been constructed. It is within these jobs that historical cost data exists which could be transformed into CoQ and represented by Feigenbaum's PAF Model. As indicated in Table 1, there were a total of 46 jobs within the population that fell within this category. Of those 46 jobs a sample of 20 jobs were selected to represent the population. In selecting the sample jobs, the following were considered: year, clarity of data, author's knowledge of the job, and the design budget. These considerations are listed in terms of their importance to the author, with the most important being the first and so on.

Year: The year represents the FY that the job began. The primary goal was to select jobs from every year to ensure the sample provided an appropriate representation of the population. Furthermore, the author attempted to spread the sample jobs as evenly as possible throughout the years. As shown in Table 2, the sample does contain jobs from every year although the sample is not as evenly distributed as was desired in that FY2013 only contains one job. This lack of distribution was primary due to the follow factors in the job selection process.

Clarity of Data: When evaluating the data it was evident that some jobs were more carefully managed in terms of tracking quality costs. As stated before the Firm does not have a mature QMS in which the quality is managed to the extent that the individual costs are tracked. When evaluating the data the author used the job budget, accounting files, and job files. This is process is explained in more detail in Section 4.

Author's knowledge of the job: For many of the jobs that were sampled the author had day-to-day experience with the job either as a design engineer or as the project manager. This intimate knowledge allows for, in the author's opinion, a more comprehensive understanding of the quality costs for the project.

Table 2 – Population Sample Breakdown

Population Sample Breakdown		
Year	Jobs	% of Sample
2009	2	10%
2010	4	20%
2011	3	15%
2012	2	10%
2013	1	5%
2014	4	20%
2015	4	20%
Count	**20**	
μ	**3**	

4.3 DATA JUSTIFICATION

Since the firm lacks a mature QMS in which CoQ is directly tracked within the accounting system the author collected financial data directly from the accounting software and using managerial judgement to determine if the costs were quality related. The following sections outline the methods used to collect the data from the existing data files available.

4.3.1 DATA COLLECTION METHODS FROM SAMPLE JOBS

Data was collected from the sample jobs in one of two ways; from the Firm's accounting software and examining the job files. The author obtained the Firm's permission prior to collecting the data and reviewing the project files. Furthermore, the data presented was reviewed with the Firm's general manager to ensure no confidential data was presented as part of this project.

4.3.1.1 Financial Data

In, or around, FY2009 the Firm's account department began using accounting management software called Spectrum® Construction Software. This software provides in-depth accounting and operation functionality while presenting data in an easy to understand format. Spectrum's® features include accounting, project management, payroll, reporting and others (Spectrum). Through the features in Spectrum®, the author was able to separate costs that were directly linked to quality appraisal costs and failure costs within the sample jobs. These quality costs evaluations are further explained in Sections 4.3.2.4.2 and 4.3.2.4.3 respectively.

4.3.1.2 Job Data

The majority of the sample jobs had detailed electronic files of the design process, quality reviews, client submittals, and corrections made during construction. By reviewing these files, the author was able to identify costs presented in the financial data review which represented quality appraisal costs or failure costs.

4.3.2 DATA COLLECTED FROM SAMPLE JOBS

In the process of gathering the financial and job data for each of the sample jobs there were a number of specific cost features relevant to the scope of this project. Specifically, information was gathered that would provide details into the CoQ for the individual projects as well as general features of the jobs that may be relevant for managerial recommendations later.

The following financial data was collected for this project: job budget, job costs, quality budget and quality costs. This information is displayed as Table 7.

4.3.2.1 Total Budget

The total budget is the total cost allotted for expenditure on that job. This budget includes consumables, labor, materials, travel, sub-contractor cost, and other miscellaneous expenses. The labor costs are referred to as a burden rate for employees. This rate includes wages, heath care, fringe benefits, and direct overhead costs. The burden rate does not include any provisions for profit. Similarly, the sub-contractor cost and project specific expenses just capture cost and have no provisions for profit. The total budget is directly captured from the financial data.

During a job setup, the project manager will separate the job into specific stages and labor tasks into phases and cost codes. These phase and cost codes are preloaded into the Spectrum® system and are used as a project management and budget-tracking feature. A list of common phase and cost codes specifically used by the Firm are shown as Table 3 and 4 respectively. The project manager has the ability to alter the cost and phase codes to fit a specific project by adding more detail.

Table 3 – Basic Phase Codes

Basic Phase Codes	
Code	Description
10	Project Management
20	Mobilization & Planning
30	Construction
40	Environmental
50	Design
60	Demobilization
70	Submittals
80	Survey

Table 4 – Basic Cost Codes

Basic Cost Codes	
Code	Description
00	Not Budgeted
01	Senior Staff
02	Staff Professional
03	Admin Support
04	CAD Operator
07	Other Labor
11	Intern
99	Proposal Cost

4.3.2.2 Total Cost

The total cost is the total amount of monies, spent by the Firm, on a specific job. These total costs may be either above or below the total budget, as outlined above. When the total costs exceed the total budgeted cost, the Firm begins seeing a reduction in profit margin. Alternately, if the total cost fall below the total budget then the Firm recognizes an increase to the total profit margin. The total costs presented in Table 7 represent the total costs spent on the sample job. The job costs are directly captured from the accounting data.

4.3.2.3 Quality Budget

The quality budget is the amount of resources that a project manager allocated for quality activities in a specific job. These activities may include plan review, attendance at plan review meeting and design quality control plan development and management. The quality budget presented in Table 7 represents the total quality budget allocated for the sample job.

To determine this value both financial and job specific data were used. It was necessary to use a combination of these data sources because quality budget reporting varies between project managers within the Firm. Currently, there is no specific cost or phase code designated for quality activities within the accounting system. By reviewing the internal job setups, cost proposals, and using best judgment the author was able to infer the quality budget of jobs in which it was not clearly defined. If the job setups and cost proposals did not clearly define the quality budget then it was assumed that all the costs associated with Cost Code 01 (Senior Staff) within Phase Code 50 (Design) were intended for quality activities.

4.3.2.4 Quality Costs

One of the objectives of this research was to evaluate the CoQ based on Feigenbaum's PAF Model. To accomplish this, the quality costs were evaluated in three groups' prevention, appraisal, and failure. The following outlines how these costs were determined from the available data.

4.3.2.4.1 Prevention

This case study classified prevention cost for the Firm as measures that include training, seminars, workshops, brown bag lunches, and higher education. The prevention cost was determined using the Firms operating budget and historical information job information. Records indicate that the Firm spends approximately $30,000 per fiscal year on labor and expenses for quality cost prevention measures. Historical data indicates that the mean of the Firms jobs per fiscal year is 48, Table 1. If it assumed that the cost of prevention is distributed equally throughout the jobs than the cost of prevention, per job, is $625. Therefore, each sample job was assigned a value of $625 for prevention cost. Table 5 provides a tabular representation of the prevention cost information.

Table 5 – Quality Cost, Prevention

Quality Cost – Prevention	
Annual Labor & Expenses (Fiscal Year)	$30,000
Mean # Jobs (Fiscal Year)	48
Cost of Prevention per Job (Calculated)	**$625**

4.3.2.4.2 Appraisal

The appraisal costs were captured from financial and job data. To ensure continuity in determining these costs, as compared to the budget, the same criteria was followed from job to job.

Appraisal cost were determined to be all costs in Phase Code 50 & Cost Code 01 from the time the job began until the design package was given to the owner. This represents cost incurred, during design, which were quality related. Any quality costs incurred after the design package was delivered to the owner are considered failure cost. Appraisal cost for each sample are displayed in Table 7

4.3.2.4.3 Failure

Failure costs were determined from financial and job data. These failure cost consisted of both labor and cash payouts to the owner or contractor which were a direct result of poor quality. Examples of poor quality mainly consist of errors in the plans or specifications within the design package. These errors are typically brought to the Firm's attention formally by way of Requests for Information and Designer Clarification

Verification Requests. This information is sometimes requested informally by discussion in the field and through email requests by the owner or contractor. Regardless of the method of request these items represent a failure in this case study.

In order to determine the failure cost financial data was collected from the time that the design package was delivered to the owner until the job was closed. Failure cost were determined to be all the cost coded to Phase Code 50 and all Cost Codes during this time with the exception of budgeted costs as outlined below. Failure costs for each sample job are displayed in Table 7.

In reviewing the job data the researcher removed any budgeted cost from the failure cost as they were planned activities in the job. These planned activities, that typically take place after the design package has been submitted to the owner, may include construction assistance, submittal reviews, and marketing cost.

4.4 DATA ANALYSIS

Once the sample data was collected and verified, it needed to be transformed and analyzed in a way that could be used to meet the objectives of the case study. The data analysis section outlines how the data was transformed and what analyses were conducted.

4.4.1 DATA TRANSFORMATION

The data collected from the financial and job records were not in a format that allowed for a direct comparison of quality cost amongst the sample jobs. The reason these cost could not be compared directly is the large variation in the sample jobs total budgets. The sample jobs total budgets varied from approximately $9,000 to $470,000. In order to display quality cost in a way that all the costs were relative to each other the data was reduced into representative ratios based on the total budget and total cost of the job. The transformed quality cost characteristics include prevention cost, appraisal cost, failure cost, quality budget, and quality cost.

The transformed data is displayed either as a ratio or a percentage throughout this case study. When displayed as a percentage it will be followed by the percentage (%) symbol. The information is displayed a percentage to make the data easier to read and understand from a management standpoint. The input values used in the following equations are presented in Table 7. All the transformed data is presented in Table 8.

4.4.1.1 Quality Budget (t)

The transformed quality budget is represented as a ratio of the total job budget.

$$\textbf{Quality Budget (t)} = \frac{\boldsymbol{Quality\ Budget}}{\boldsymbol{Total\ Budget}} \qquad \text{[Equation 1]}$$

4.4.1.2 CoQ (t)

The transformed CoQ is a function of two equations. The first is a summation of the prevention, appraisal, and failure quality cost to represent the CoQ. The final transformed CoQ is represented as a ratio of the CoQ and total job cost.

$$\textbf{CoQ} = \textbf{Prevention Cost} + \textbf{Appraisal Cost} + \textbf{Failure Cost} \qquad \text{[Equation 2]}$$

$$\textbf{CoQ (t)} = \frac{\textbf{CoQ}}{\textbf{Total Cost}} \qquad \text{[Equation 3]}$$

4.4.1.3 Prevention Cost (t)

The transformed prevention cost is represented as a ratio of the total job cost.

$$\textbf{Prevention Cost (t)} = \frac{\textbf{Prevention Cost}}{\textbf{Total Cost}} \qquad \text{[Equation 4]}$$

4.4.1.4 Appraisal Cost (t)

The transformed appraisal cost is represented as a ratio of the total job cost.

$$\textbf{Appraisal Cost (t)} = \frac{\boldsymbol{Appraisal\ Cost}}{\boldsymbol{Total\ Cost}} \qquad \text{[Equation 5]}$$

4.4.1.5 Failure Cost (t)

The transformed failure cost is represented as a ratio of the total job cost.

$$\textbf{Failure Cost (t)} = \frac{\boldsymbol{Failure\ Cost}}{\boldsymbol{Total\ Cost}} \qquad \text{[Equation 6]}$$

4.4.2 SOFTWARE PACKAGES

The software packages use collect, organize, display, and analyze data include Microsoft® Word and Excel, STATGRAPHICS®, and Spectrum®

The Microsoft Suite 2010 including Word and Excel were used for report development (Word©) and data entry, transformations, tables, select graphing (Excel©).

STATAGRAPHICS® Centurion XVII, Version 17.1.08 (64-bit), Copyright © 1982-2014 Statpoint Technologies, Inc. was used for data analysis, non-parametric testing, regression analysis, and CoQ Graphing.

Spectrum®, Version 13.16, Copyright © 1988-2015 Dexter & Chaney, Inc. was used to retrieve the financial data from the Firm's accounting database.

4.4.3 General Summary Statistics

Some general summary statistics were developed to provide general information about the data that was used throughout the analysis. This general statistical information includes; count, median, minimum value, maximum value, range, lower quartile, upper quartile, interquartile range, median range (first through third quartile), and box and whisker plot display.

4.4.4 Non-Parametric Testing for Size Effect

Due to the large range in Job Budget values, with a minimum of $9,217 and a maximum of $472,597, a testing for size effect was conducted on the transformed data. The size effect testing was done to determine if it was appropriate to evaluate all the sample jobs as one data set.

Prior to testing, the author developed criteria to identify job sizes in one of three categories: small, medium, and large. This criterion was established by evaluating the minimum and maximum values in the data set and establishing bin widths that would, to the extent possible, evenly spread the sample jobs through the job size categories. The budget range criteria and count of job samples, which fell into each category, are displayed in Table 6.

Table 6 – Job Size Categories

Job Size Categories		
Job Size	Budget Range ($)	Count
Small (S)	< 100K	10
Medium (M)	100K - 200K	5
Large (L)	> 200K	5

Testing for size effect was done by comparing the medians of all the transformed data outlined in Section 4.4.1. When all three job size categories were evaluated as a whole, the Kruskal-Wallis Test was used. If the Kruskal-Wallis Test indicated that the medians might not be equal then the Mann-Whitney (Wilcoxon) W-test was used to evaluate pairs of data.

The Kruskal-Wallis Test parameters are as follows:

H_o: $Median_1 = Median_2 = Median_3$

H_a: At least one Median is <u>NOT</u> Equal.

Mann-Whitney (Wilcoxon) W-test parameters are as follows

H_o: $Median_1 = Median_2$

H_a: Medians are not <u>NOT</u> Equal.

4.4.5 Non-Parametric Testing of CoQ Spending Trends

As part of the system optimization process it was important to compare the existing Quality Budget (t) with the CoQ (t). This was important for two reasons. The first was to demonstrate whether the existing CoQ spending followed the established quality budget. The second was to evaluate if the optimization model would exceed the existing CoQ conditions.

The non-parametric test used to evaluate the difference in the medians was the Signed Rank Test. This test was chosen because the population is paired and measured as oppose to the Sign Test for which the populations must be independent.

Signed Rank Test parameters are as follows:

H_o: $Median_1 - Median_2 = 0$

H_a: The difference in the medians does NOT equal 0.

4.4.6 NON-PARAMETRIC TESTING FOR CORRELATION OF APPRAISAL AND FAILURE COST

To evaluate whether a monotonic correlation exists between the Appraisal Cost (t) and Failure Cost (t) data the non-parametric Spearman Rank Correlations test was performed. The Spearman rank correlations coefficients range between -1 and +1 and measure the strength of the association between the variables. The Spearman coefficients are computed from the ranks of the data values rather than from the values themselves.

Spearman Rank Correlations parameters are as follows:

H_o: There is NO statistically significant non-zero correlation between data sets.

H_a: A statistically significant non-zero correlation exists between data sets.

4.5 MODEL DEVELOPMENT

This case study included the development of two models to analyze CoQ, the Feigenbaum PAF Model and the Juran and Gryna Optimum Quality Cost Model. This section outlines the development of those models.

4.5.1 FEIGENBAUM'S PAF MODEL

The Feigenbaum model was developed using the following transformed quality cost data; prevention, appraisal, and failure costs. This data is displayed as both general statistics and a box and whisker plot showing which provides a visual representation of the spending trends. The general statistics are shown in Section 5.5.2 and the box and whisker plot is displayed as Figure 11.

4.5.2 Juran and Gryna Optimum Quality Cost Model

The Juran and Gryna Optimum Quality Cost Model displays the CoQ spending in such a way as management can make informed decisions about how to maximize profits in regards to quality activities, based on the Feigenbaum PAF Model.

This model was developed by creating equations that could be used to detail the CoQ based on the amount of defects, or in this case failures. The equations for cost data were developed using regression analysis and assumptions as outlined below. This model is displayed as Figure 13.

4.5.2.1 Median Job Budget

The model evaluates the CoQ of the median job, as it relates to the Firm. Since all the transformed quality costs relate to specific jobs the median job budget was chosen. The median job budget is displayed in Table 9.

4.5.2.2 Prevention Cost

The prevention cost was assumed to be constant for each job as outlined in Section 4.3.2.4.1. In this model the prevention cost are not dependent on the amount of defects in product.

4.5.2.3 Appraisal Cost

The appraisal cost was determined using the regression model software in STATGRPHICS®. A simple regression model was created with Appraisal Cost (t) and Failure Cost (t) as the parameters. A comparison of twenty-seven alternative models was evaluated and the model with the highest correlation coefficient was selected. The regression model included an equation, which represented the best-fit line to describe the relationship between the data sets. This equation was then paired with the median Job Budget to present the Appraisal Cost as a function of Defects, or Failures. The regression model and final equation are presented as Figure 12 and Equation 9, respectively.

4.5.2.4 Failure Cost

Failure costs represent the internal failure cost which the Firm carries when defects occur in the project. The failure cost does not include any external failure cost or intangible cost. Through the author's research and data collection no information could be found, or developed, that provided a direct link to defects during construction and internal failure cost. Therefore an equation to represent failure cost was developed that loosely related to the Kano Model developed by Noriaki Kano in the 1980's do describe customer satisfaction.

It appeared that Kano's model was exponential in nature and through iteration; an equation was developed that appeared to relate defects to failure cost using the author's judgment as senior manager. The equation developed to represent failure cost is displayed as Equation 7.

$$\boldsymbol{Failure\ Cost\ (t)} = (\mathbf{e}^{\mathbf{2*Defects}} - \mathbf{1}) \qquad \text{[Equation 7]}$$

4.6 SYSTEM OPTIMIZATION

System understanding and optimization is another major outcome of this project. By developing the Feigenbaum and Juran / Gryna Models we are able to evaluate the existing system and quantify what may occur if the CoQ's were optimized.

First, the Feigenbaum Model of the existing CoQ was constructed and displayed graphically. This is model is displayed as Figure 14.

The Juran / Gryna Model developed for the median job budget provides an understating of what the optimum quality level should be to minimize the CoQ. In evaluating this model, the first item to note is that the optimum amount of defects in your product is identified. The regression model for Appraisal Cost (t) vs. Failure Cost (t) is then evaluated at that optimum defect level to get the corresponding Appraisal Cost ratio for the budget. The optimized prevention costs are assumed not to change from the previously established constant.

With the optimization information from the Juran / Gryna Model an optimized Feigenbaum Model was developed to compare median existing system and the optimized system. This information is displayed as Figure 15.

A direct comparison of the two models is displayed graphically as Figure 16.

A graph of the CoQ was also developed for all the years within the case study. This graph is displayed as Figure 17.

4.7 DISCUSS MANAGERIAL ISSUES

Using the information developed as part of the case study the author will discuss the managerial issues as they relate to the existing CoQ and QMS.

4.8 LIMITATION OF RESEARCH

This case study contains limitation for which the data would be valid. The following are possible factors which may attribute to the limitation of this research.

1. All the sampling was selective and some of the job data was collected by inference and the judgment of the author.

2. The quality cost for failure represents only cost felt by the Firm. Failure cost incurred by the owner or contractor were not considered in the failure cost data. Also, intangible cost were not considered as part of this case study.

3. By nature CEDS is a unique process. This case study attempted to classify CoQ based on models that are typically reserved for the manufacturing industry.

4. The conclusion about the CoQ is unique to this firm and the data set collected as part of this case study.

CHAPTER 5 - RESULTS

The following are the results of the data sampling, analysis, model development, and system optimization.

5.1 DATA COLLECTION

The final data set that is a direct result of the data collection procedures outlined in Sections 4.2 and 4.3 and is displayed as Table 7.

Table 7 - Sample Job Data Set

Sample Jobs Financial Data										
						Quality Costs				
Job	Year	Size	Total Budget	Total Cost	Quality Budget	Prevention	Appraisal	Failure	CoQ
1	2009	S	$63,719	$63,719	$2,330	$625	$2,330	$5,000	$7,955
2	2009	L	$210,110	$211,113	$18,600	$625	$15,183	$4,300	$20,108
3	2010	M	$112,808	$72,887	$15,904	$625	$14,674	$1,600	$16,899
4	2010	M	$103,879	$92,698	$8,950	$625	$8,950	$2,500	$12,075
5	2010	S	$19,823	$16,619	$2,310	$625	$53	$1,000	$1,678
6	2010	M	$158,092	$95,315	$6,569	$625	$992	$5,000	$6,617
7	2011	S	$55,689	$51,820	$4,200	$625	$1,500	$2,900	$5,025
8	2011	L	$219,885	$174,350	$25,597	$625	$32,354	$2,000	$34,979
9	2011	L	$472,597	$351,975	$17,600	$625	$3,000	$70,000	$73,625
10	2012	M	$153,433	$73,408	$2,166	$625	$2,166	$5,000	$7,791
11	2012	L	$447,977	$334,710	$39,930	$625	$8,198	$22,694	$31,517
12	2013	L	$450,490	$379,377	$15,150	$625	$5,984	$19,858	$26,467
13	2014	S	$18,932	$13,774	$1,200	$625	$119	$2,000	$2,744
14	2014	S	$55,765	$60,000	$2,600	$625	$500	$3,500	$4,625
15	2014	S	$9,217	$10,882	$450	$625	$300	$150	$1,075
16	2014	M	$182,457	$175,650	$5,200	$625	$3,500	$2,500	$6,625
17	2015	S	$22,113	$21,025	$588	$625	$350	$0	$975
18	2015	S	$27,514	$15,700	$1,668	$625	$500	$1,000	$2,125
19	2015	S	$28,130	$19,062	$1,668	$625	$850	$800	$2,275
20	2015	S	$87,871	$56,527	$5,500	$625	$1,500	$500	$2,625
Minimum			**$9,217**	**$10,882**	**$450**	**$625**	**$53**	**$0**	**$975**
Maximum			**$472,597**	**$379,377**	**$39,930**	**$625**	**$32,354**	**$70,000**	**$73,625**

5.2 DATA ANALYSIS

The following sections outline the results of the data analysis process. The results displayed include the data transformation results, general summary statistics, and non-parametric testing. This information was used in the CoQ Model development and to aid in the decision making process.

5.2.1 DATA TRANSFORMATION

The transformed quality cost data as described in Sections 4.4.1 is displayed as Table 8 as a percentage.

Table 8 - Transformed Quality Cost Data

Transformed Quality Cost Data					
Job	**Quality Budget (t)**	**Quality Cost (t)**	**Prevention Cost (t)**	**Appraisal Cost (t)**	**Failure Cost (t)**
1	3.7%	12.5%	1.0%	3.7%	7.8%
2	8.9%	9.5%	0.3%	7.2%	2.0%
3	14.1%	23.2%	0.9%	20.1%	2.2%
4	8.6%	13.0%	0.7%	9.7%	2.7%
5	11.7%	10.1%	3.8%	0.3%	6.0%
6	4.2%	6.9%	0.7%	1.0%	5.2%
7	7.5%	9.7%	1.2%	2.9%	5.6%
8	11.6%	20.1%	0.4%	18.6%	1.1%
9	3.7%	20.9%	0.2%	0.9%	19.9%
10	1.4%	10.6%	0.9%	3.0%	6.8%
11	8.9%	9.4%	0.2%	2.4%	6.8%
12	3.4%	7.0%	0.2%	1.6%	5.2%
13	6.3%	19.9%	4.5%	0.9%	14.5%
14	4.7%	7.7%	1.0%	0.8%	5.8%
15	4.9%	9.9%	5.7%	2.8%	1.4%
16	2.8%	3.8%	0.4%	2.0%	1.4%
17	2.7%	4.6%	3.0%	1.7%	0.0%
18	6.1%	13.5%	4.0%	3.2%	6.4%
19	5.9%	11.9%	3.3%	4.5%	4.2%
20	6.3%	4.6%	1.1%	2.7%	0.9%
Minimum	**1.4%**	**3.8%**	**0.2%**	**0.3%**	**0.0%**
Maximum	**14.1%**	**23.2%**	**5.7%**	**20.1%**	**19.9%**

5.2.2 GENERAL SUMMARY STATISTICS

General statistical information about the data sets include; count, median, minimum value, maximum value, range, lower quartile, upper quartile, interquartile range, Median Range from the 1st to the 3rd quartile, and box and whisker plot display. See following page for continuation.

5.2.2.1 Job Budget

The general summary statistics and box and whisker plot for Job Budget are shown in Table 9 and Figure 4, respectively.

Table 9 - Job Budget General Statistics

Job Budget	
Count	20
Median	$95,875
Median Range [1 - 3 quartile]	$41,909 - $196,284
Minimum	$9,217
Maximum	$472,597
Range	$463,380
Lower quartile	$27,822
Upper quartile	$196,284
Interquartile range	$168,462

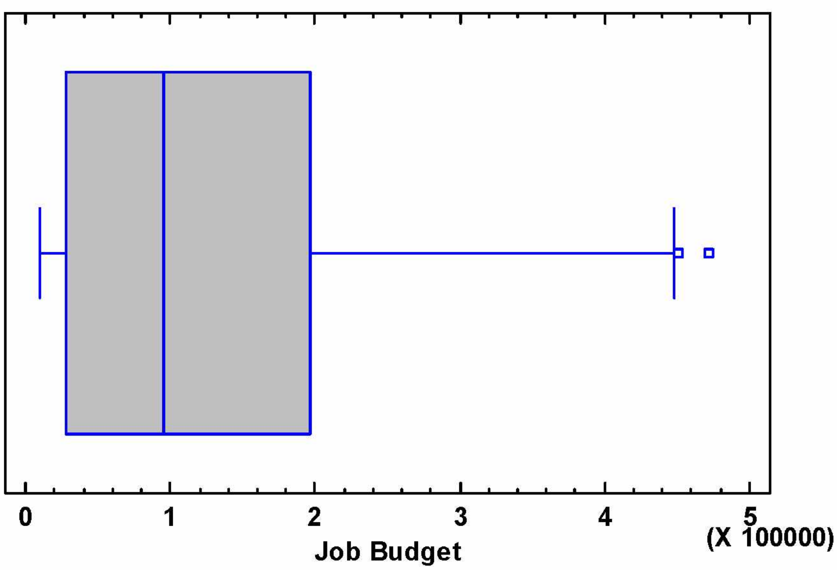

Figure 4 – Job Budget Box-and-Whisker Plot

5.2.2.2 Quality Budget (t)

The general summary statistics and box and whisker plot for Quality Budget (t) are shown in Table 10 and Figure 5, respectively.

Table 10 - Quality Budget (t) General Statistics

Quality Budget (t)	
Count	20
Median	6.0%
Median Range [1 - 3 quartile]	3.9% - 8.7%
Minimum	1.4%
Maximum	14.1%
Range	12.7%
Lower quartile	3.7%
Upper quartile	8.7%
Interquartile range	5.0%

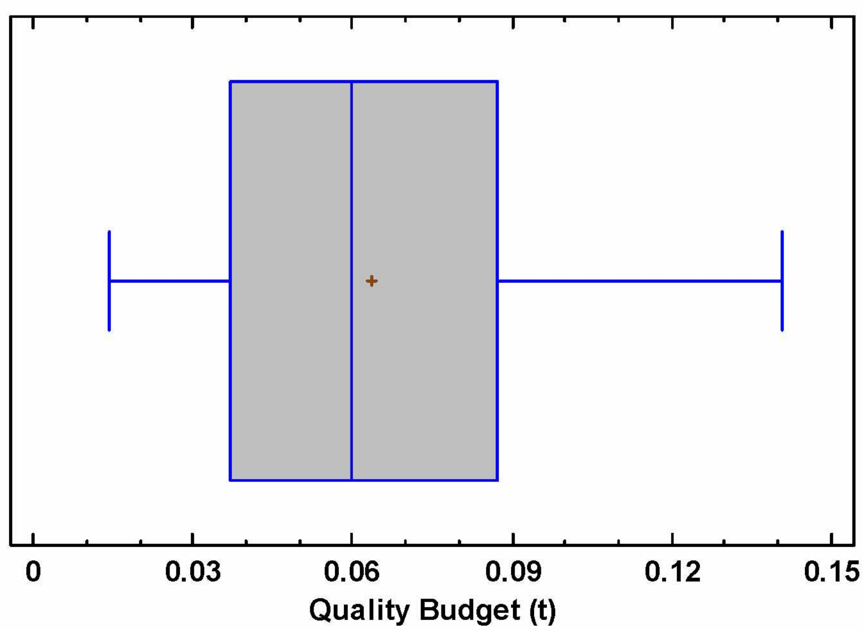

Figure 5 - Quality Budget (t) Box-and-Whisker Plot

5.2.2.3 CoQ (t)

The general summary statistics and box and whisker plot for CoQ (t) are shown in Table 11 and Figure 6, respectively.

Table 11 - CoQ (t) General Statistics

CoQ (t)	
Count	20
Median	10.0%
Median Range [1 - 3 quartile]	8.6% - 13.3%
Minimum	3.8%
Maximum	23.2%
Range	19.4%
Lower quartile	7.3%
Upper quartile	13.3%
Interquartile range	5.9%

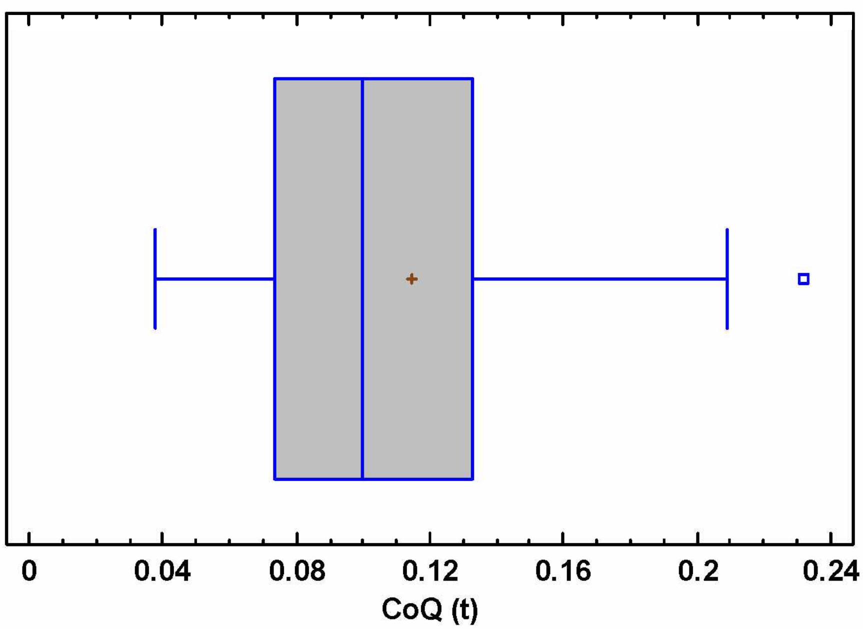

Figure 6 - CoQ (t) Box-and-Whisker Plot

5.2.2.4 Prevention Cost (t)

The general summary statistics and box and whisker plot for Prevention Cost (t) are shown in Table 12 and Figure 7, respectively.

Table 12 - Prevention Cost (t) General Statistics

Prevention Cost (t)	
Count	20
Median	0.9%
Median Range [1 - 3 quartile]	0.4% - 2.1%
Minimum	0.2%
Maximum	5.7%
Range	5.6%
Lower quartile	0.4%
Upper quartile	3.1%
Interquartile range	2.8%

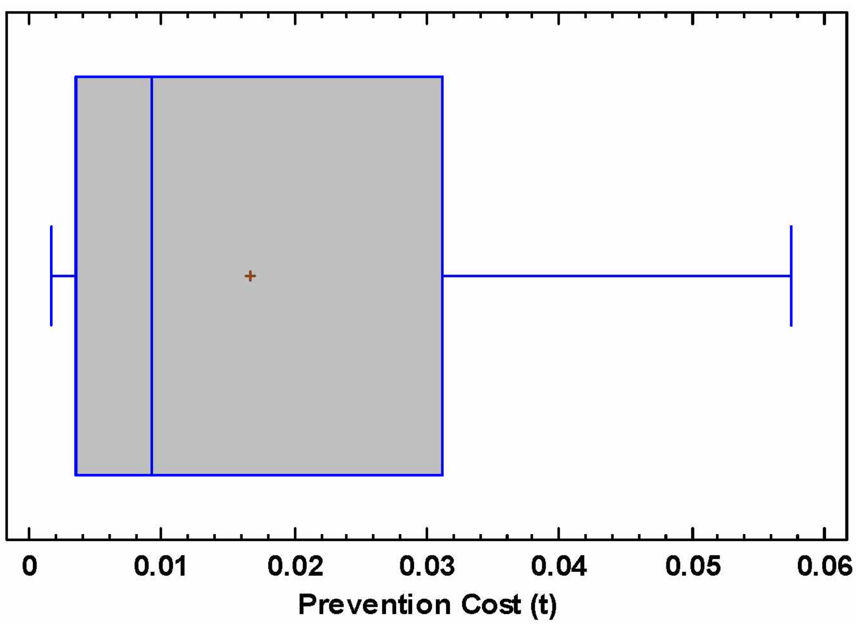

Figure 7 - Prevention Cost (t) Box-and-Whisker Plot

5.2.2.5 Appraisal Cost (t)

The general summary statistics and box and whisker plot for Appraisal Cost (t) are shown in Table 13 and Figure 8, respectively.

Table 13 – Appraisal Cost (t) General Statistics

Appraisal Cost (t)	
Count	20
Median	2.7%
Median Range [1 - 3 quartile]	1.6% - 3.4%
Minimum	0.3%
Maximum	20.1%
Range	19.8%
Lower quartile	1.3%
Upper quartile	4.1%
Interquartile range	2.7%

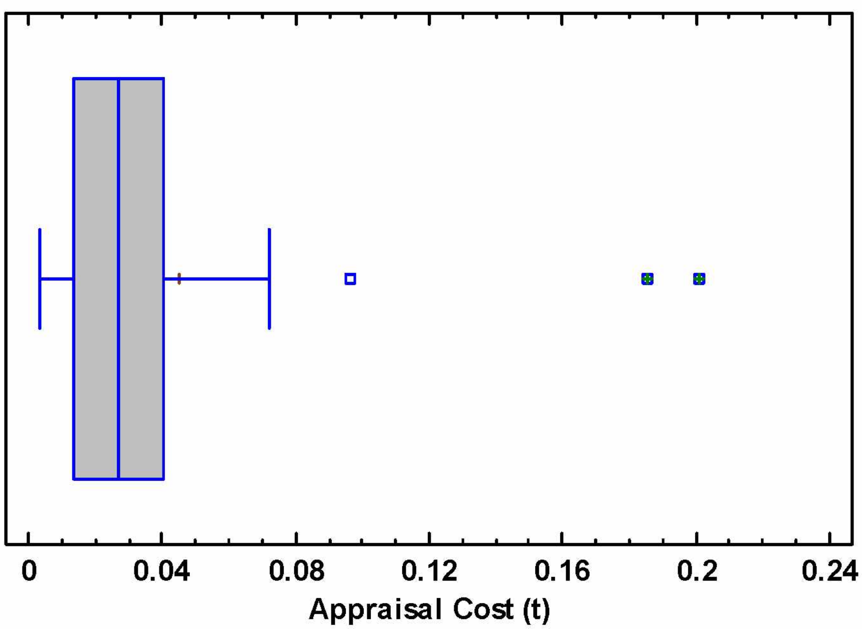

Figure 8 - Appraisal Cost (t) Box-and-Whisker Plot

5.2.2.6 Failure Cost (t)

The general summary statistics and box and whisker plot for Failure Cost (t) are shown in Table 14 and Figure 9, respectively.

Table 14 - Failure Cost (t) General Statistics

Failure Cost (t)	
Count	20
Median	5.2%
Median Range [1 - 3 quartile]	2.0% - 6.2%
Minimum	0.0%
Maximum	19.9%
Range	19.9%
Lower quartile	1.7%
Upper quartile	6.6%
Interquartile range	4.8%

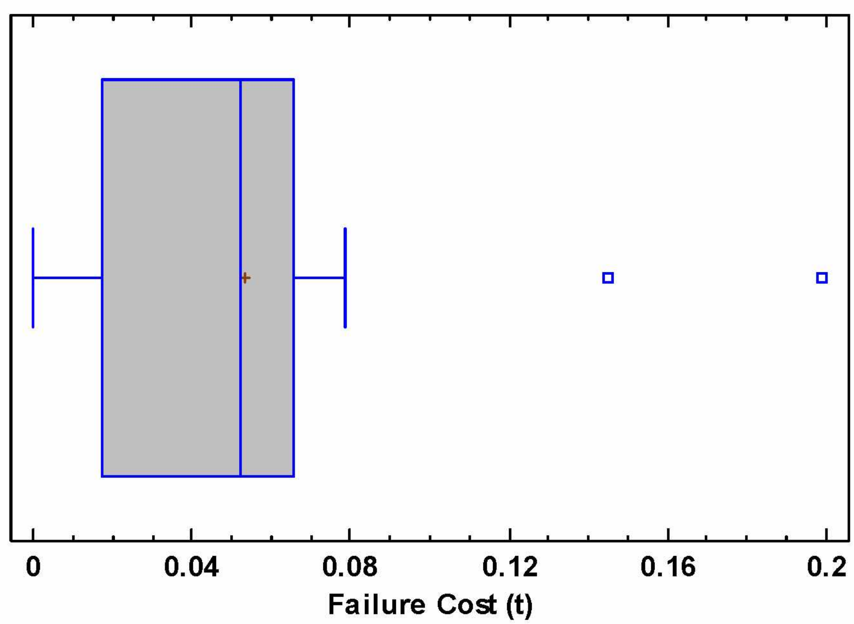

Figure 9 - Failure Cost (t) Box-and-Whisker Plot

5.2.3 NON-PARAMETRIC TESTING FOR SIZE EFFECT

The Kruskal-Wallis test was performed to determine if the median values of the transformed quality cost were affected by the size of the Total Budget. At 95% confidence we would choose not to reject (DNR) the H_o for all quality costs with the exception of the Prevention Cost (t). The test results are presented in Table 15.

Table 15 – Kruskal-Wallis Test of Medians

Kruskal-Wallis Test Comparison of Medians at 95% Confidence	
Quality Budget (t)	DNR (0.7169)
CoQ (t)	DNR (0.9218)
Prevention Cost (t)	Reject (0.0003)
Appraisal Cost (t)	DNR (0.5349)
Failure Cost (t)	DNR (0.9218)

The prevention cost (t) were then evaluated using the Mann-Whitney W-test to determine if the difference in medians existing just between one pair of the sizes. Base on the results of this test we choose to reject the H_o and conclude that the medians are not equal among all the job sizes.

Table 16 – Mann-Whitney W-test

Mann-Whitney (Wilcoxon) W-test Comparison of Medians at 95% Confidence			
	Job Size		
	Small = Medium	Medium = Large	Small = Large
Prevention Cost (t)	Reject (0.0027)	Reject (0.0216)	Reject (0.0027)

Intuitively it makes sense that the medians of the transformed prevention cost are not equal among all the job sizes this is because the prevention cost are constant for every job.

5.2.4 NON-PARAMETRIC TESTING OF COQ SPENDING TRENDS

In order to determine if the existing CoQ and QMS system was function correct based on the assigned quality budget a Signed Rank test was done comparing the median Quality Budget (t) and median CoQ (t).

The Signed Rank test yields a P-value of 0.0004; therefore, we should reject the H_o at 95% confidence and conclude that the difference between the Quality Budget (t) and CoQ (t) is equal to 0. This result is evident in the Box-and-Whisker plot of the Quality Budget (t) and the Coq (t) show as Figure 10.

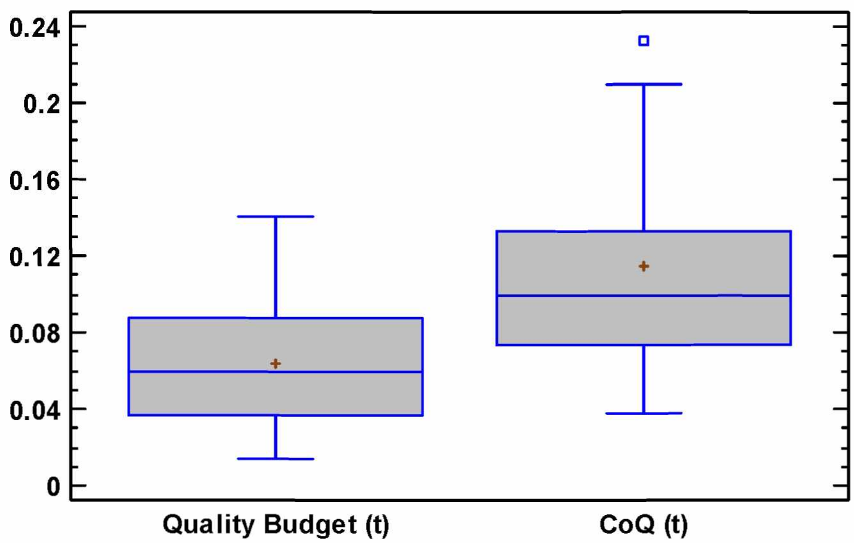

Figure 10 – Box-and-Whisker Plot of Quality Budget (t) and CoQ (t)

5.2.5 NON-PARAMETRIC TESTING FOR CORRELATION OF APPRAISAL AND FAILURE COST

Table 17 shows the Spearman Rank Correlations between Appraisal Cost (t) and Failure Cost (t). At 95% confidence, we should not reject the H_o that there is no statistically significant non-zero correlation exists between data sets.

Some items to note about the correlation information in Table 17 are that the correlation between Appraisal Cost (t) and Failure Cost (t) is negative. This indicates that as the appraisal cost increase the failure cost decrease. This is what we would expect as appraisal is directly linked to the amount of review design package receives.

Although the p-value indicates that we should not reject that there is not statistical significance in the correlation other factors in this case study indicate that there is. Particularly with the development of the regression model.

Table 17 – Spearman Rank Correlations

Spearman Rank Correlations		
	Appraisal Cost (t)	Failure Cost (t)
Appraisal Cost (t)		-0.3414
		(20)
		0.1368
Failure Cost (t)	-0.3414	
	(20)	
	0.1368	

5.3 MODEL DEVELOPMENT

The following sections present the model development as described in Section 4.5.

5.3.1 FEIGENBAUM'S PAF MODEL

Feigenbaum's PAF Model for median quality cost is shown in Figure 11 in the form of a box-and-whisker plot. This view allows the reader to evaluate the individual transformed quality cost. Of particular interest is the high level ratio of failure cost. This may indicate that the QMS is not doing an adequate job of removing errors prior to releasing the design packages to the client.

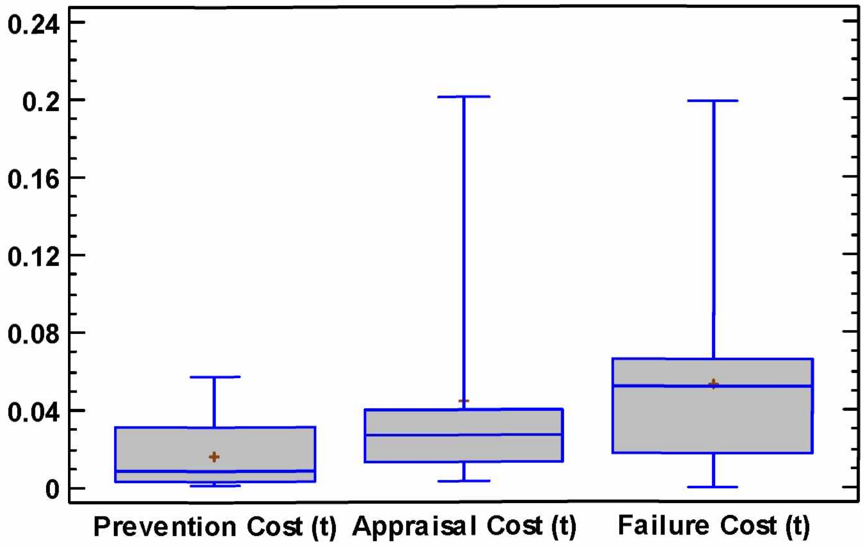

Figure 11 – Feigenbaum's PAF Model

5.3.2 JURAN AND GRYNA OPTIMUM QUALITY COST MODEL

The Juran and Gryna Optimum Quality Cost Model was developed from the Feigenbaum PAF model and a regression analysis of the Appraisal Cost (t) as a function of Failure Cost (t). The results of the model development are shown in this section.

5.3.2.1 Regression Analysis

The result of the regression analysis performed using STATGRAPHICS® is displayed as Table 18 and Figure 12. The best fit model for this data set was determined to be an exponential regression with a correlation value of -0.4840 and an R-Squared of 23.43%.

Table 18 – Comparison of Regression Models

Comparison of Alternative Models		
Model	**Correlation**	**R-Squared**
Exponential	-0.4840	23.43%
Logistic	-0.4813	23.16%
Logarithmic-Y square root-X	-0.4457	19.86%
Square root-Y	-0.4385	19.23%
Logarithmic-Y squared-X	-0.4091	16.74%
Double square root	-0.4070	16.57%
Linear	-0.3767	14.19%
Reciprocal-Y	0.3665	13.43%
Reciprocal-Y square root-X	0.3608	13.02%
Square root-X	-0.3584	12.84%
Squared-Y	-0.3026	9.16%
Squared-Y square root-X	-0.3010	9.06%
Reciprocal-Y squared-X	0.3009	9.06%
Squared-X	-0.2872	8.25%
Double squared	-0.2117	4.48%
--Remaining Tests--	<no fit>	

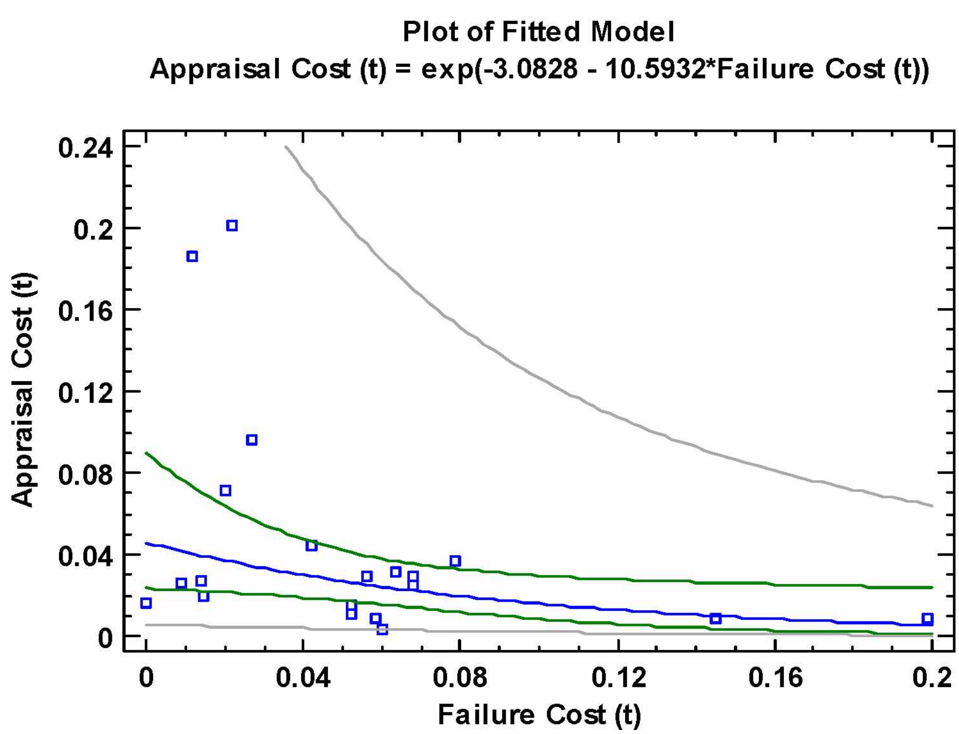

Figure 12 – Regression of Appraisal Cost (t) vs. Failure Cost (t)

5.3.2.2 Summary of Juran and Gryna Optimum Quality Cost Model Inputs

The following is a summary of the Juran and Gryna Optimum Quality Cost Model inputs some.

5.3.2.2.1 Prevention Cost

The prevention costs for the model were defined in Section 4.5.2.2 and are displayed as Equation 8.

$$\boldsymbol{Prevenion\ Cost} = \$\mathbf{625} \qquad \text{[Equation 8]}$$

5.3.2.2.2 Appraisal Cost

The appraisal costs were determined using the regression analysis defined in Section 4.5.2.3. The equation for determining appraisal cost

$$\textbf{Failure Cost} = \boldsymbol{Total\ Budget} * (\mathbf{e}^{(-3.0828-10.5932*\boldsymbol{Defects})}) \qquad \text{[Equation 9]}$$

5.3.2.2.3 Failure Cost

The failure costs for the model were defined in Section 4.5.2.4 and are displayed as Equation 10. Failure Cost (t) is displayed in Equation 7.

$$\textbf{Failure Cost} = \boldsymbol{Total\ Budget} * \boldsymbol{Faiure\ Cost\ (t)} \qquad \text{[Equation 10]}$$

5.3.2.3 Juran and Gryna Optimum Quality Cost Model Output

The output of the Juran and Gryna Optimum Quality Cost Model is displayed shown as Figure 13.

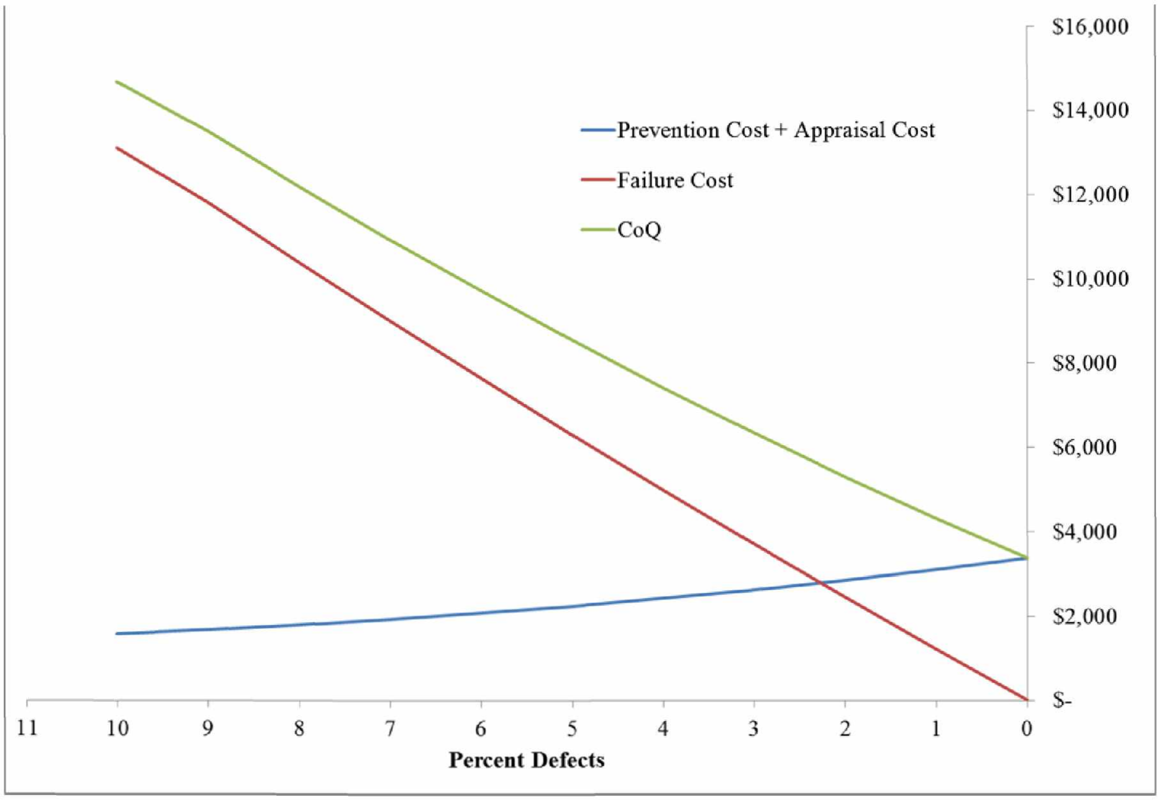

Figure 13 - Juran and Gryna Optimum Quality Cost Model Output

5.3.2.4 Discussion

Based on the Juran and Gryna Optimum Quality Cost Model the optimum level of defects for the median job is zero. This is not unexpected since the defects are so closely linked to the appraisal cost and the failure cost diminishes rapidly as the defects decrease.

5.4 SYSTEM OPTIMIZATION

For the system optimization, the CoQ of the existing system was compared to the CoQ of the optimized system based on the modeled results from Section 5.3. The systems are shown with displaying the upper and bounds which are limited by the 1st and

3rd quartiles of the median values. The upper and lower bound of the CoQ for the optimized system are assumed to have an inter-quartile range of 50% less than the existing system.

5.4.1 CoQ of Existing System

The CoQ values of a median job with the upper and lower bounds are shown in Table 19. The CoQ for the existing system, displaying the upper and lower bounds, is shown graphically in Figure 14.

An important thing to note in the graphical representation of this data is the large variation from the upper bound to the lower bounds of the median values. This may indicate that the existing QMS system is not providing consistent control of the CoQ process.

Table 19 – CoQ Values of Existing System

CoQ of Existing System						
	Upper Bound		Median		Lower Bound	
CoQ	11.7%	$7,020	8.9%	$5,365	4.0%	$2,400
Prevention Cost	2.1%	$1,260	1.0%	$625	0.4%	$240
Appraisal Cost	3.4%	$2,040	2.7%	$1,620	1.6%	$960
Failure Cost	6.2%	$3,720	5.2%	$3,120	2.0%	$1,200

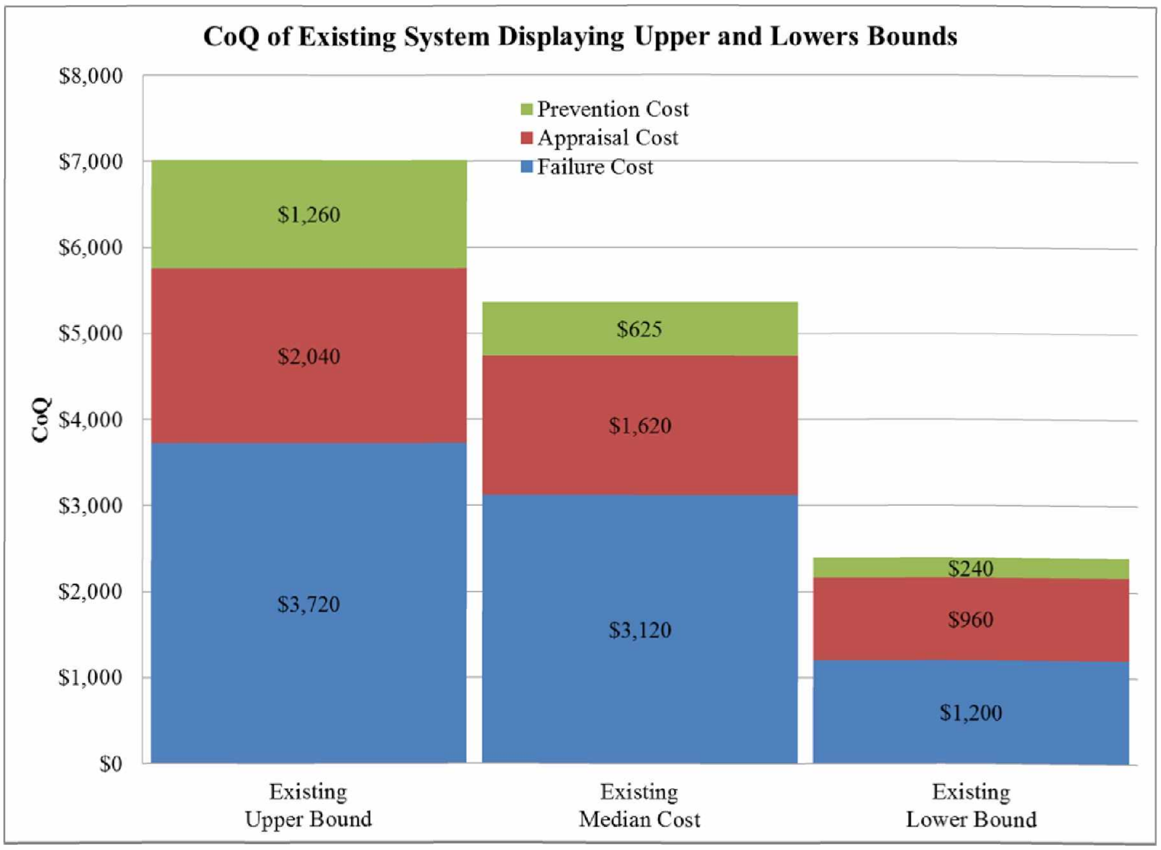

Figure 14 – CoQ Graph of Existing System

5.4.2 CoQ of Optimized System

The CoQ values of a median job with the upper and lower bounds are shown in Table 20. The CoQ for the optimized system, displaying the upper and lower bounds, is shown graphically in Figure 15.

Table 20 – CoQ Values of Optimized System

CoQ of Optimized System						
	Upper Bound		Median		Lower Bound	
CoQ	7.5%	$4,471	6.1%	$3,643	4.7%	$2,821
Prevention Cost	1.6%	$943	1.0%	$625	0.7%	$433
Appraisal Cost	4.9%	$2,928	4.5%	$2,718	4.0%	$2,388
Failure Cost	1.0%	$600	0.5%	$300	0.0%	$0

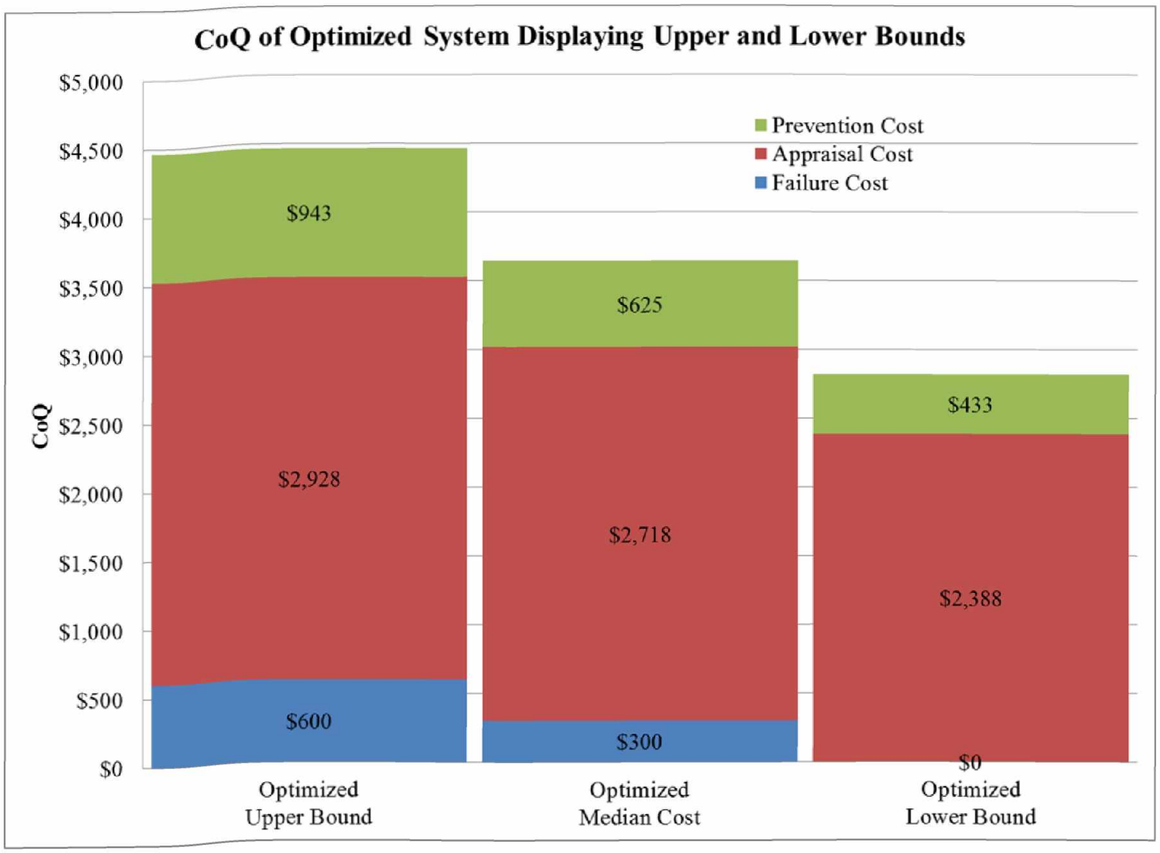

Figure 15 – CoQ Graph of Optimized System

5.4.3 COMPARISON OF EXISTING AND OPTIMIZED SYSTEMS

The median value of the CoQ for the median job using the existing system is \$5,365, or 8.9% of the total budget. Likewise, the median value of the CoQ for the median job using the optimized system is \$3,643, or 6.1% of the total budget.

When compared side by side, it is apparent that the optimized system may have benefits in the reduction of CoQ. One of the most important features to note about the comparison of these systems is the dramatic reduction in failure cost for the optimized system.

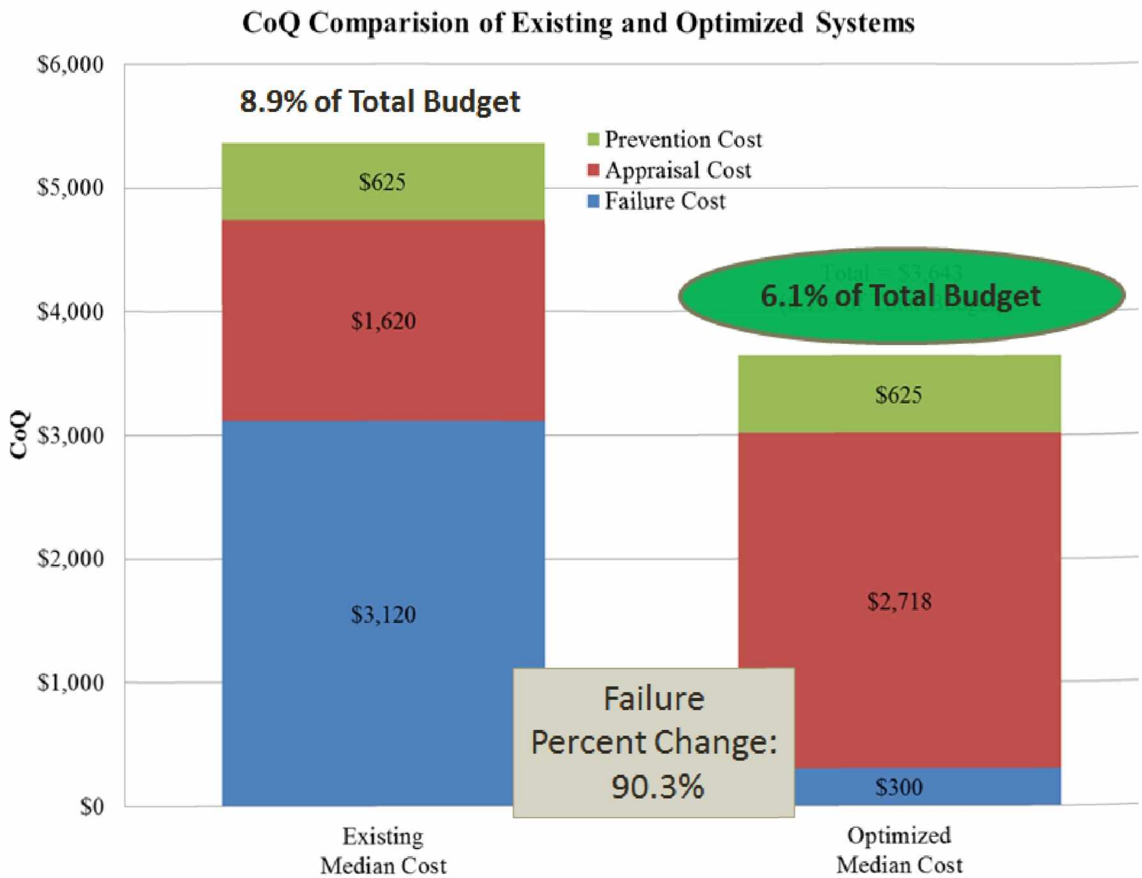

Figure 16 – CoQ Graph of Existing and Optimized System

5.4.4 Comparison of Existing and Optimized Systems

The median CoQ (t) trend of the Firm is displayed in Figure 17. The optimized system is shown on the far right side of the graph.

An interesting feature to note on the graph is that the Failure Cost (t) appears to consistently be the greatest contributing factor to the overall CoQ. From the year 2011 until 2015 it appears that the overall CoQ (t) has been decreasing but is still dominated by Failure Cost (t).

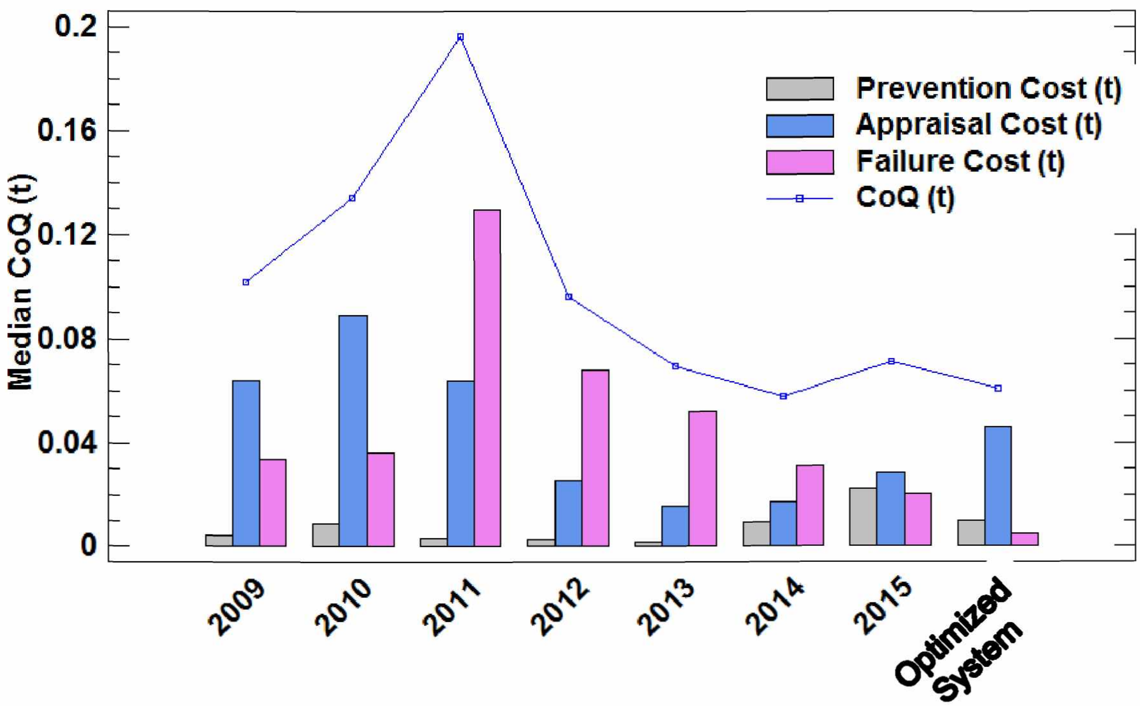

Figure 17 – Median CoQ (t) by Year and Optimized System

CHAPTER 6 - CONCLUSIONS

The following are the conclusion research objectives as outlined in Chapter 3.

1. Evaluate if job size has an effect on CoQ, i.e. size effect.

   The overall budget size does not affect the CoQ for jobs within the Firm, at 95% confidence, with the exception of prevention cost which are a constant and not a function of the overall budget.

2. Evaluate if appraisal cost are related to failure cost.

   At 95% confidence we should reject the H_o that there is a statistically significant non-zero correlation exists between data sets. However, based on the modeling and regression analysis there is an obvious correlation.

3. Evaluate the firms current CoQ, based on Feigenbaum's PAF model using historical data and descriptive statistics.

   The ratio of median value of the Firms prevention, appraisal, and failure cost as compared to the total budget displayed as a percentage are 1.0%, 2.7%, and 5.2% respectively.

4. Use the data collected in the Feigenbaum's PAF Model; develop a CoQ model outlining an optimized system which minimizes CoQ as defined by Juran and Gryna.

   The minimum CoQ was determined to be zero defects.

5. Evaluate if Firm's current CoQ is optimized based on the Juran and Gryna model.

   Using the Signed Rank test it was demonstrated that the firms current CoQ is not optimized, or within the parameter of the existing quality budget, at 95% confidence.

6. Evaluate the quantitative data and provide managerial recommendations based on observations.

The managerial recommendations are presented in Section 7.

In general the outcomes of this case study provided valuable information for further development of the Firms QMS.

CHAPTER 7 - MANAGERIAL ISSUES AND DISCUSSION

This chapter outlines the managerial issues and recommendations that were a direct result of this case study. In addition, a discussion section is included to outline further research that may be conducted on this subject.

7.1 MANAGERIAL ISSUES

Based on this case study it is apparent that the Firms current CoQ is not currently running at an optimum level. The failure rate was determined to be 5.2% of the overall budget with appraisal cost at 2.7% of the overall budget. Although there was not a statistical significance showing that an increased appraisal cost would decrease the failure cost the data did suggest that it would occur. The optimized model of the CoQ system predicts that if the appraisal cost were increased to 4.5% of the overall budget the failure cost could be reduced to 0.5% of the overall budget. This change in the QMS system would provide an overall reduction in the CoQ by 2.8% of the job budget. The benefit of this reduction would not only be felt by the Firm with increased profits but by the owners and contractors building the jobs. It is important to note that the reduction in failure or errors will also have effects on the intangible areas of quality cost as defined by Juran (1951).

During the literature review the use of ISO 9001 as a QMS for CEDS was the most common and received support from both the Government of NSW and ASCE. It is recommended that ISO 9001 be used starting point for the improvement of the Firms existing QMS. With the implementation of the new QMS the Firm should continue to measure quality based on the steps outline in this report but with an improved quality tracking system to better define the quality costs.

7.2 DISCUSSION

There is much room to expand on this research. The most obvious would be to track the internal and external failure cost during construction. This would provide great insight into the relationship between the two. This tracking may be done with new software such as Building Information Modeling (BIM) or other advanced tracking software. Beach et al. (2013) suggested that could computing linked with BIM could be an effective way to measure and monitor a project. The link of BIM and cloud computing could be taken one step further and paired with a project management software such as Spectrum® to provide a fully integrated managerial accounting view of the project that would give real time updates as the project progressed.

Another area that could be expanded on would be the implementation of other QMS into CEDS. Marzouk et al (2012) suggests that the implementation of QMS lean principles could improve utilization of the design process by 40%. There may be other programs that could have an effect on the CEDS QMS.

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A CASE STUDY OF EVALUATING THE IMPACT OF COST OF QUALITY FOR CIVIL ENGINEERING DESIGN SERVICES IN A SMALL CORPORATION

Engineering Science Management Program
University of Alaska Anchorage

Presented By:
Isaac Pearson, B.S.

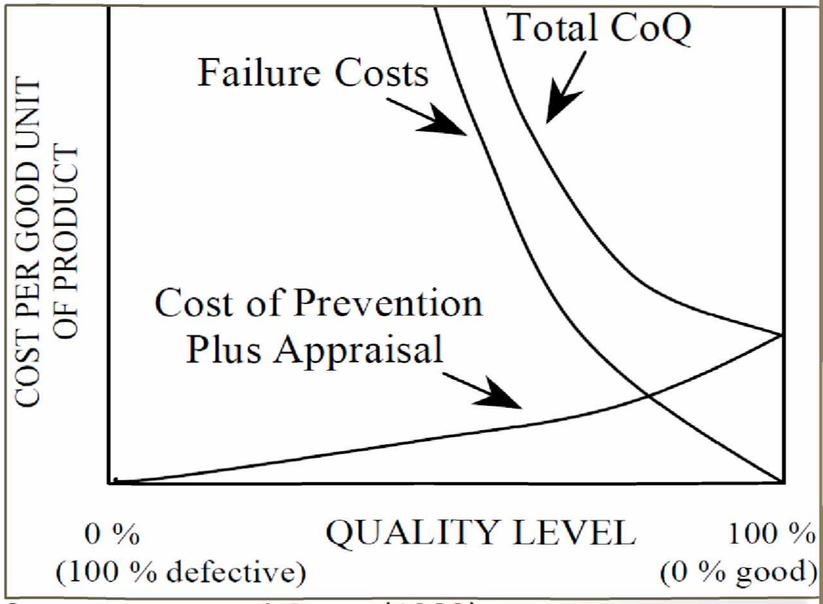
Fall 2015

Cost of Quality (CoQ) History

- Discussions in late 1940's, American Society for Quality Control (ASQC).
- Joseph Juran (1951) published *Quality Control Handbook*.
- Lesser (1954) linked CoQ to Managerial Accounting.
- Armand Feigenbaum (1956) revolutionized quality thinking by developing the Seven Stage Industrial Cycle and PAF Model.
- In 1961, ASQC Quality Cost Committee was established.
- Crosby (1979) popularized CoQ with *Quality is Free*.

Cost of Quality Definitions

- Tangible Cost & Intangible Cost (Juran, 1951)
- Feigenbaum Quality Costs, PAF Model, (Feigenbaum, 1956)
  - Prevention Cost
  - Appraisal Cost
  - Failure Cost
    - **<u>Internal & External</u>**, Freeman (1960).
- Juran and Gryna (1988)
  Model of Optimum Quality Cost



Source: Juran and Gryna (1988)

DEFINITIONS

- Civil Engineering Design Services
  - Professional services which result in plans and specifications to construct facilities to be used by the public.
  - Facilities include; roads, bridges, and water & wastewater systems.
- Small Corporation (Enterprise)
  - Less than 50 employees and less $11M in revenue (Centre for Strategy & Evaluation Services, 2012).
- Firm
  - Corporation evaluated in this case study.
- Quality Management System (QMS)
  - Any system for which there is a formal method for collecting and reporting useful data that will allow an organizations management to effectively make decisions about performance (Mauch, 2010).

QMS FOR ENGINEERING DESIGN SERVICES

- QMS History
  - Closely linked to the CoQ History.
  - Rooted in Japan with help of Deming in 1950's.
    - Continuous Improvement Model.
  - Juran in 1960's.
    - Trilogy – Planning, Control, and Improvement.
  - Many others…

- QMS in Civil Engineering Design Services
  - In 1987, International Organization for Standardization (ISO) 9000 was published.
  - ISO 9001 implemented in Engineering Design (Niekerk, 2011).
  - ISO 9001 linked to Civil Engineering by Botha (2012).
  - ISO 9001 used by the Government of New South Wales (2013).
  - ISO 9001 approved by American Society of Civil Engineers (ASCE, 2014).

THE NEED FOR QMS

- Sanderson & Ricketts (1988) urges the Institution of Civil Engineers to initiate QMS.
- Hamzah (1993) found that 40-50% of failures were due to design.
- Habrecht (1994) calls for QMS to reduce overhead in firms.
- Love and Heng (2000) found 51% of failures were due to design.
- Management of engineering design is most neglected area in construction process. (Marzouk et al., 2012).
- Williams (2013) found lack of engineering design management was major contributor to failure.

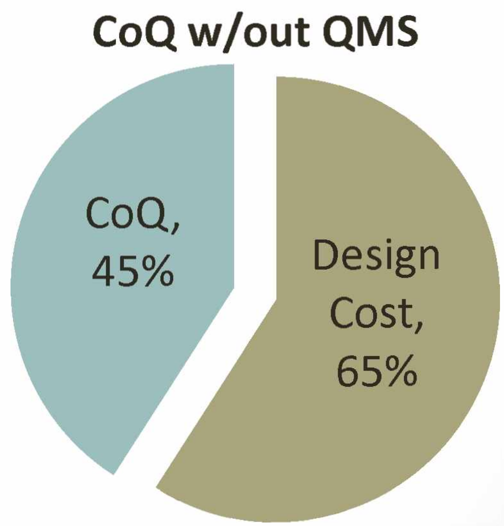
THE BENEFITS OF QMS

Design

- Davis et al.(1989) found 47% of design time is quality based.
- Loduca (2011) CoQ in engineering design ranges from 45-65% of total revenues w/out QMS.
- QMS can improve quality by 82% (Niekerk, 2011).

Construction

- Cnuddle (1991) found that design error failures account for 4.6% - 9.2% of total project cost.
- Burati et. al.(1992) found that design error failures account for 9.5% of total project cost.



Source: Loduca (2011)

RESEARCH OBJECTIVES

1. Evaluate if job size has an effect on CoQ.
2. Evaluate if there is a correlation between appraisal and failure cost.
3. Evaluate if CoQ spending is within Quality Budget.
4. Evaluate CoQ using Feigenbaum's quality cost.
5. Use the Feigenbaum's costs to develop a CoQ model outlining an optimized system which minimizes CoQ.
6. Evaluate if Firm's current CoQ is optimized.
7. Evaluate the quantitative data and provide Managerial Accounting recommendations based on observations.

METHODOLOGY – OVERVIEW

- Data Sampling
- Data Justification
- Data Analysis
  - Non-Parametric Testing
    - Kruskal-Wallis Test
    - Mann-Whitney (Wilcoxon) W-test
    - Singed Rank Test
    - Spearman Rank Correlations
- Model Development & Optimizations
  - Feigenbaum's Quality Costs
  - Minimum Quality Cost (Juran and Gryna 1988)
- Discuss the Managerial Issues

Methodology – Data Sampling

Population Information

- 7-years (2009 – 2015)
- 46 Jobs

Historical Job Data			
Year	All Jobs	Design Jobs	Design Jobs (Constructed)
2009	66	24	9
2010	35	18	7
2011	29	7	3
2012	56	16	11
2013	53	11	4
2014	70	23	8
2015	30	9	4
Count	339	108	46
μ	48	15	7

METHODOLOGY – DATA SAMPLING

Subjective Sampling

- Sampling Criterion
  - Year of Job
  - Clarity of Data
  - Researchers knowledge of job
  - Design Budget
  - Sample Size

METHODOLOGY – DATA SAMPLING

Sample Information

- 20 Jobs
- **43%** of Population

Population Sample Breakdown		
Year	Jobs	% of Sample
2009	2	10%
2010	4	20%
2011	3	15%
2012	2	10%
2013	1	5%
2014	4	20%
2015	4	20%
Count	20	
μ	3	14%

METHODOLOGY – DATA JUSTIFICATION

- Financial data gathered DIRECTLY from accounting software Spectrum®.
  - Overall Budget
  - Overall Cost
- Financial data gathered from Spectrum® using to managerial judgment to infer data values.
  - Quality Budget
  - Quality Costs
    - Prevention (PC)
    - Appraisal (AC)
    - Failure (FC)
- The Firm's CoQ = PC + AC + FC
  - Only measures tangible cost and internal failures.

METHODOLOGY – DATA JUSTIFICATION

- Prevention Cost
  - Established from operations budget.

Quality Cost - Prevention	
Labor & Expenses (Fiscal Year)	$30,000
Mean # Jobs (Fiscal Year)	48
Cost of Prevention per Job (Calculated)	$625

Source: The Firm

METHODOLOGY – DATA JUSTIFICATION

- Appraisal Cost
  - Time: Beginning of design to beginning of construction.
  - Used phase and cost codes in Spectrum® system.

Basic Phase Codes	
Code	Description
10	Project Management
20	Mobilization & Planning
30	Construction
40	Environmental
50	**Design**
60	Demobilization
70	Submittals
80	Survey

Source: The Firm

Appraisal Cost

Basic Cost Codes	
Code	Description
00	Not Budgeted
01	**Senior Staff**
02	Staff Professional
03	Admin Support
04	CAD Operator
07	Other Labor
11	Intern
99	Proposal Cost

Source: The Firm

METHODOLOGY – DATA JUSTIFICATION

- Failure Cost
  - Time: Construction only.
  - Used phase and cost codes in Spectrum®.
    - Pulled **ALL** cost data from Phase 50 after release of project to owner.
- Removed all budgeted cost after design completion
  - Construction assistance
  - Submittal reviews
  - Marketing cost
- Remaining Failure examples
  - Requests for Information (RFI)
  - Designer Clarification Verification Requests (DCVR)
  - Any drawing or specification rework after release to client

Sample Jobs Financial Data

Job	Year	Size	Total Budget	Total Cost	Quality Budget	Quality Costs: Prevention	Appraisal	Failure	CoQ
1	2009	Small	$63,719	$63,719	$2,330	$625	$2,330	$5,000	$7,955
2	2009	Large	$210,110	$211,113	$18,600	$625	$15,183	$4,300	$20,108
3	2010	Medium	$112,808	$72,887	$15,904	$625	$14,674	$1,600	$16,899
4	2010	Medium	$103,879	$92,698	$8,950	$625	$8,950	$2,500	$12,075
5	2010	Small	$19,823	$16,619	$2,310	$625	$53	$1,000	$1,678
6	2010	Medium	$158,092	$95,315	$6,569	$625	$992	$5,000	$6,617
7	2011	Small	$55,689	$51,820	$4,200	$625	$1,500	$2,900	$5,025
8	2011	Large	$219,885	$174,350	$25,597	$625	$32,354	$2,000	$34,979
9	2011	Large	$472,597	$351,975	$17,600	$625	$3,000	$70,000	$73,625
10	2012	Medium	$153,433	$73,408	$2,166	$625	$2,166	$5,000	$7,791
11	2012	Large	$447,977	$334,710	$39,930	$625	$8,198	$22,694	$31,517
12	2013	Large	$450,490	$379,377	$15,150	$625	$5,984	$19,858	$26,467
13	2014	Small	$18,932	$13,774	$1,200	$625	$119	$2,000	$2,744
14	2014	Small	$55,765	$60,000	$2,600	$625	$500	$3,500	$4,625
15	2014	Small	$9,217	$10,882	$450	$625	$300	$150	$1,075
16	2014	Medium	$182,457	$175,650	$5,200	$625	$3,500	$2,500	$6,625
17	2015	Small	$22,113	$21,025	$588	$625	$350	$0	$975
18	2015	Small	$27,514	$15,700	$1,668	$625	$500	$1,000	$2,125
19	2015	Small	$28,130	$19,062	$1,668	$625	$850	$800	$2,275
20	2015	Small	$87,871	$56,527	$5,500	$625	$1,500	$500	$2,625
Minimum			$9,217	$10,882	$450	$625	$53	$0	$975
Maximum			$472,597	$379,377	$39,930	$625	$32,354	$70,000	$73,625

METHODOLOGY – DATA ANALYSIS

- All transformed data denoted with (t).

$$\text{Quality Budget }(t) = \frac{Quality\ Budget}{Total\ Budget}$$

Quality Budget

$$\text{Quality Cost }(t) = \frac{Total\ Quality\ Cost}{Total\ Cost}$$

CoQ

$$\text{Prevention Cost }(t) = \frac{Prevention\ Cost}{Total\ Cost}$$

$$\text{Appraisal Cost }(t) = \frac{Appraisal\ Cost}{Total\ Cost}$$

$$\text{Failure Cost }(t) = \frac{Failure\ Cost}{Total\ Cost}$$

Itemized CoQ

Transformed Quality Cost Data					
Job	Quality Budget (t)	Quality Cost (t)	Prevention Cost (t)	Appraisal Cost (t)	Failure Cost (t)
1	3.7%	12.5%	1.0%	3.7%	7.8%
2	8.9%	9.5%	0.3%	7.2%	2.0%
3	14.1%	23.2%	0.9%	20.1%	2.2%
4	8.6%	13.0%	0.7%	9.7%	2.7%
5	11.7%	10.1%	3.8%	0.3%	6.0%
6	4.2%	6.9%	0.7%	1.0%	5.2%
7	7.5%	9.7%	1.2%	2.9%	5.6%
8	11.6%	20.1%	0.4%	18.6%	1.1%
9	3.7%	20.9%	0.2%	0.9%	19.9%
10	1.4%	10.6%	0.9%	3.0%	6.8%
11	8.9%	9.4%	0.2%	2.4%	6.8%
12	3.4%	7.0%	0.2%	1.6%	5.2%
13	6.3%	19.9%	4.5%	0.9%	14.5%
14	4.7%	7.7%	1.0%	0.8%	5.8%
15	4.9%	9.9%	5.7%	2.8%	1.4%
16	2.8%	3.8%	0.4%	2.0%	1.4%
17	2.7%	4.6%	3.0%	1.7%	0.0%
18	6.1%	13.5%	4.0%	3.2%	6.4%
19	5.9%	11.9%	3.3%	4.5%	4.2%
20	6.3%	4.6%	1.1%	2.7%	0.9%
Minimum	**1.4%**	**3.8%**	**0.2%**	**0.3%**	**0.0%**
Maximum	**14.1%**	**23.2%**	**5.7%**	**20.1%**	**19.9%**

METHODOLOGY – DATA ANALYSIS

Software Used

- Microsoft Excel® 2010
  - Data Entry
  - Transformations
  - Tables
  - Graphing

- STATAGRAPHICS® Centurion XVII
  - Non-Parametric Testing
  - Regression Analysis
  - CoQ Graphing

METHODOLOGY – DATA ANALYSIS

<u>Non-Parametric Testing for Size Effect</u>

- Samples were broken into 3 job sizes based on budget.
  -Researcher Defined.

Job Size Parameters		
Job Size	**Budget Range ($)**	**Count**
Small	< 100K	10
Medium	100K - 200K	5
Large	> 200K	5

- Kruskal-Wallis Test
  - H_o: $Median_1 = Median_2 = Median_3$
  - H_a: At least one Median is <u>NOT</u> Equal.
- Mann-Whitney (Wilcoxon) W-test
  - H_o : $Median_1 = Median_2$
  - H_a : Medians are not <u>NOT</u> Equal.

METHODOLOGY – DATA ANALYSIS

Non-Parametric Testing of CoQ Spending

- Compare Quality Budget (t) and Quality Cost (t).
- Used to determine if CoQ spending followed the budget.

- Signed Rank Test
  - H_o : $Median_1 - Median_2 = 0$
  - H_a : The difference in the medians does NOT equal 0.

METHODOLOGY – DATA ANALYSIS

<u>Non-Parametric Testing of Correlation</u>

- Compare Appraisal Cost (t) to Failure Cost (t)
- Is there a link between the two?

- Spearman Rank Correlations
  - H_o : There is <u>NO</u> statistically significant non-zero correlation between data sets.
  - H_a : A statistically significant non-zero correlation exists between data sets.

METHODOLOGY – MODEL DEVELOPMENT

CoQ Model Development

- Juran and Gryna (1988) Model of Optimum Quality Cost
- Developed CoQ model for a job with \$60K Total Budet.
  - Prevention Cost
    - \$625 / project
  - Appraisal Cost
    - Determined from regression model:

      Appraisal Cost (t) vs. Failure Cost (t)
  - Failure Cost
    - Assumed to be exponential and related to Kano Model
    - $Failure\ Cost\ =\ Budget\ (e^{2\ (Defect\ rate)} - 1)$

METHODOLOGY – SYSTEM OPTIMIZATION

1. Determine optimum quality cost using CoQ Model.
2. Evaluate against firms current quality level using Feigenbaum Cost.
3. Evaluate Firms quality spending trends.
4. Provide recommendations for system improvement.

LIMITATIONS OF RESEARCH

- Inferences of data values were made by researcher.
- Failure quality cost data only reflects Firms cost.
  - Failure cost of contractor or owner were not considered.
  - Intangible cost were not considered as part of the analysis.
- By nature, civil engineering design is unique to each job. The researcher attempted to evaluate CoQ based on models that are typically reserved for manufacturing.
- Conclusions are unique to this Firm.

RESULTS – NON-PARAMETRIC TESTING

- Tested for size effect
- Kruskal-Wallis Test

Kruskal-Wallis Test Comparison of Medians at 95% Confidence	
Prevention Cost (t)	Reject (0.0003)
Appraisal Cost (t)	DNR (0.7029)
Failure Cost (t)	DNR (0.4480)
Quality Budget (t)	DNR (0.7169)
Quality Cost (t)	DNR (0.9217)

DNR = Do Not Reject

- Mann-Whitney (Wilcoxon) W-test
  - Size matters at 95% Confidence
    - Prevention Cost (t)

Mann-Whitney (Wilcoxon) W-test Comparison of Medians at 95% Confidence			
	Job Size		
	Small = Medium	Medium = Large	Small = Large
Prevention Cost (t)	Reject (0.0027)	Reject (0.0119)	Reject (0.0026)

RESULTS – NON-PARAMETRIC TESTING

- Compare Appraisal Cost (t) to Failure Cost (t)
- Spearman Rank Correlations
  - P-Value = 0.1368; **Do Not** Reject the Null Hypothesis at 95% confidence. No non-zero correlation.

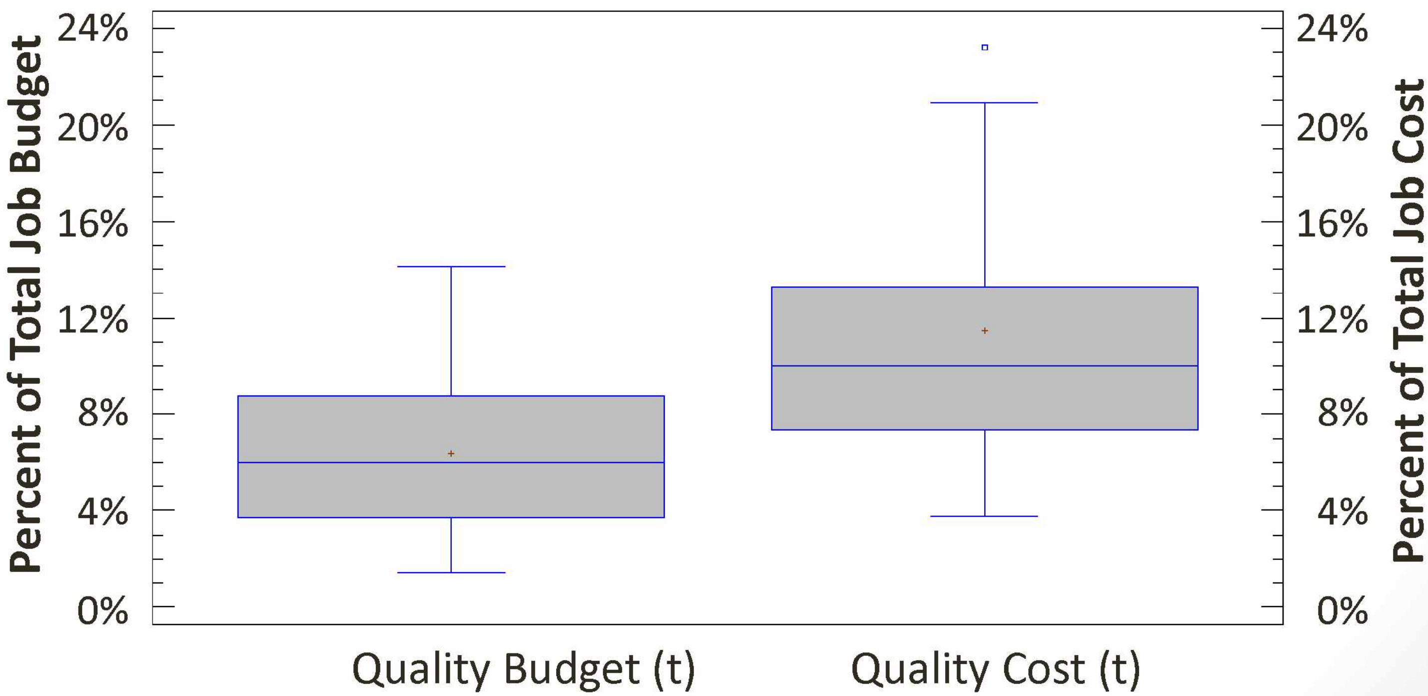
Spearman Rank Correlations

	Appraisal Cost (t)	Failure Cost (t)	
Appraisal Cost (t)		-0.3414	Correlation
		(20)	Count
		0.1368	P-value
Failure Cost (t)	-0.3414		
	(20)		
	0.1368		

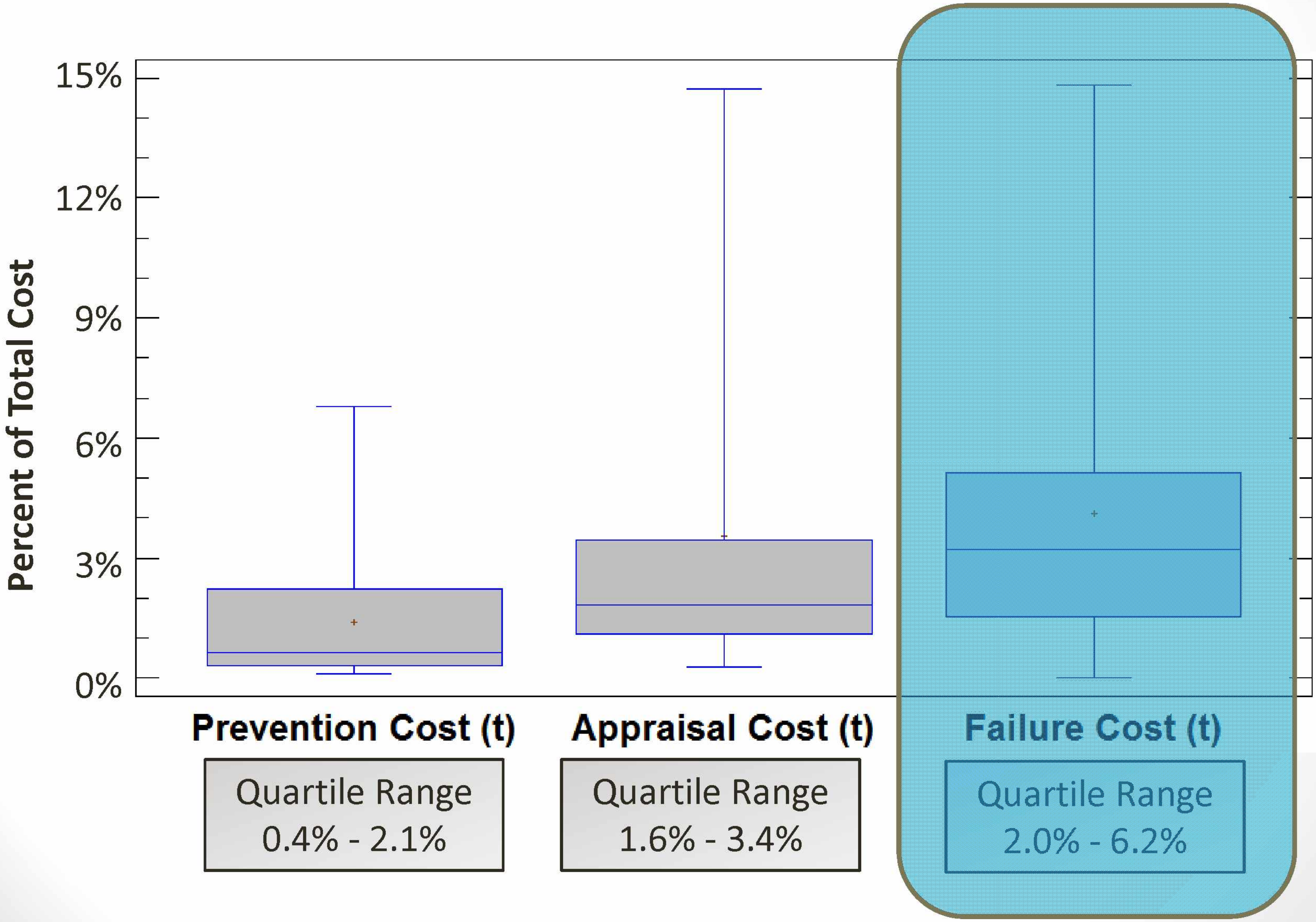
  - A negative correlation exist between Appraisal Cost (t) and Failure Cost (t) indicating that as appraisal increases failure decreases.

RESULTS – NON-PARAMETRIC TESTING

- Tested for differences in Quality Budget and Spending.
- Signed Rank Test
  - P-Value = 0.0003; Reject Null Hypothesis.
  - Difference is evident below.

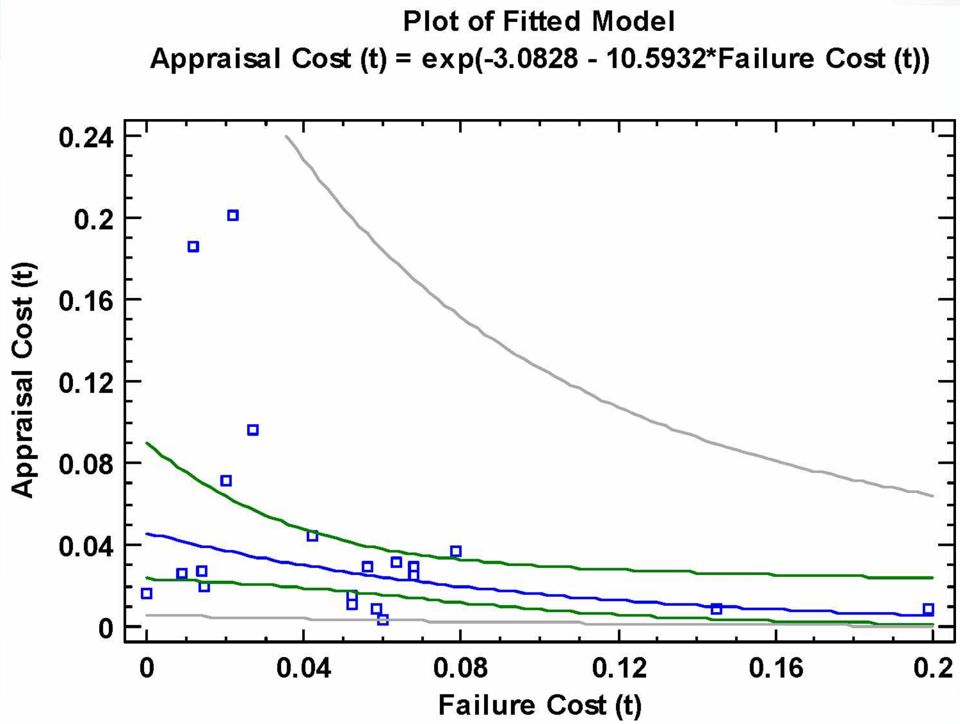


RESULTS – FEIGENBAUM'S COST

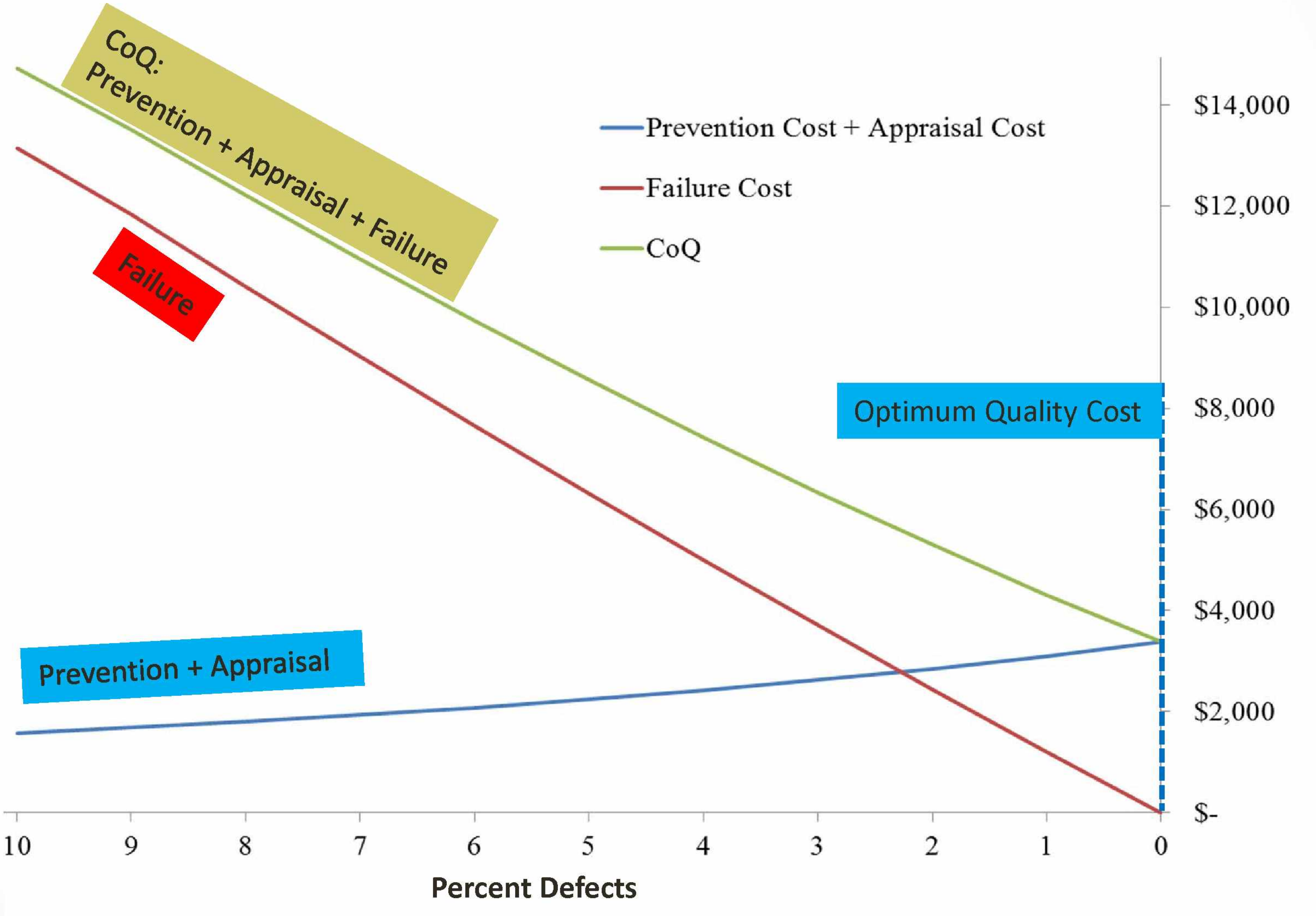


RESULTS – REGRESSION ANALYSIS

Comparison of Alternative Models		
Model	Correlation	R-Squared
Exponential	-0.4840	23.43%
Logistic	-0.4813	23.16%
Logarithmic-Y square root-X	-0.4457	19.86%
Square root-Y	-0.4385	19.23%
Logarithmic-Y squared-X	-0.4091	16.74%
Double square root	-0.4070	16.57%
Linear	-0.3767	14.19%
Reciprocal-Y	0.3665	13.43%
Reciprocal-Y square root-X	0.3608	13.02%
Square root-X	-0.3584	12.84%
Squared-Y	-0.3026	9.16%
Squared-Y square root-X	-0.3010	9.06%
Reciprocal-Y squared-X	0.3009	9.06%
Squared-X	-0.2872	8.25%
Double squared	-0.2117	4.48%
--Remaining Tests--	<no fit>	



Results – CoQ Model



Results – System Optimization

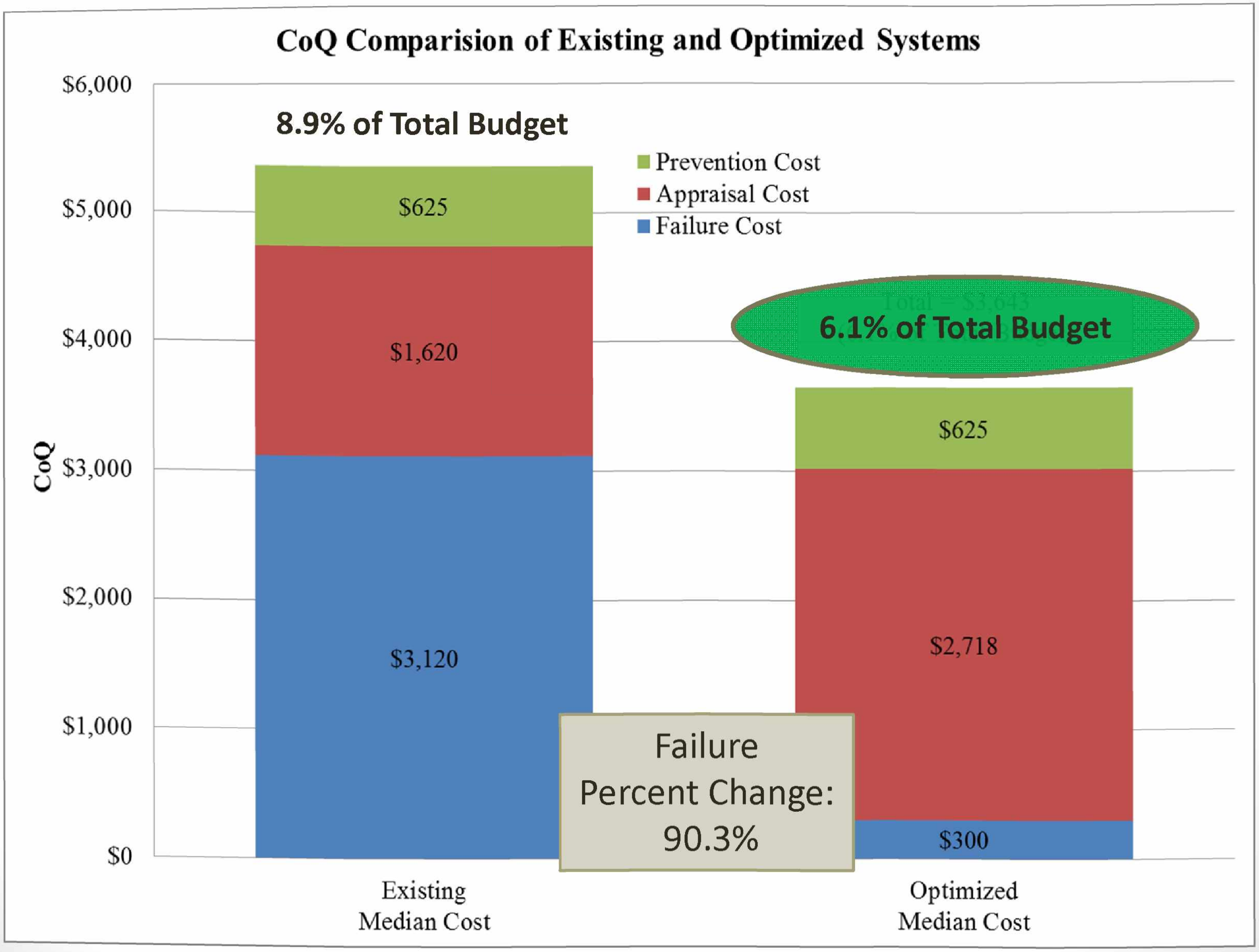
- Optimum (minimum) Quality Cost = **0 Defects (Failure)**
  - **Presenters Note: 0 Defects is not realistic; use 0.005 for models.**

- Current Defect Rate of System:
  - Median Value = **5.2%**

- To achieve 0.005 Defects Appraisal Cost is predicted to be **4.5%** of the overall budget, according to the regression model.

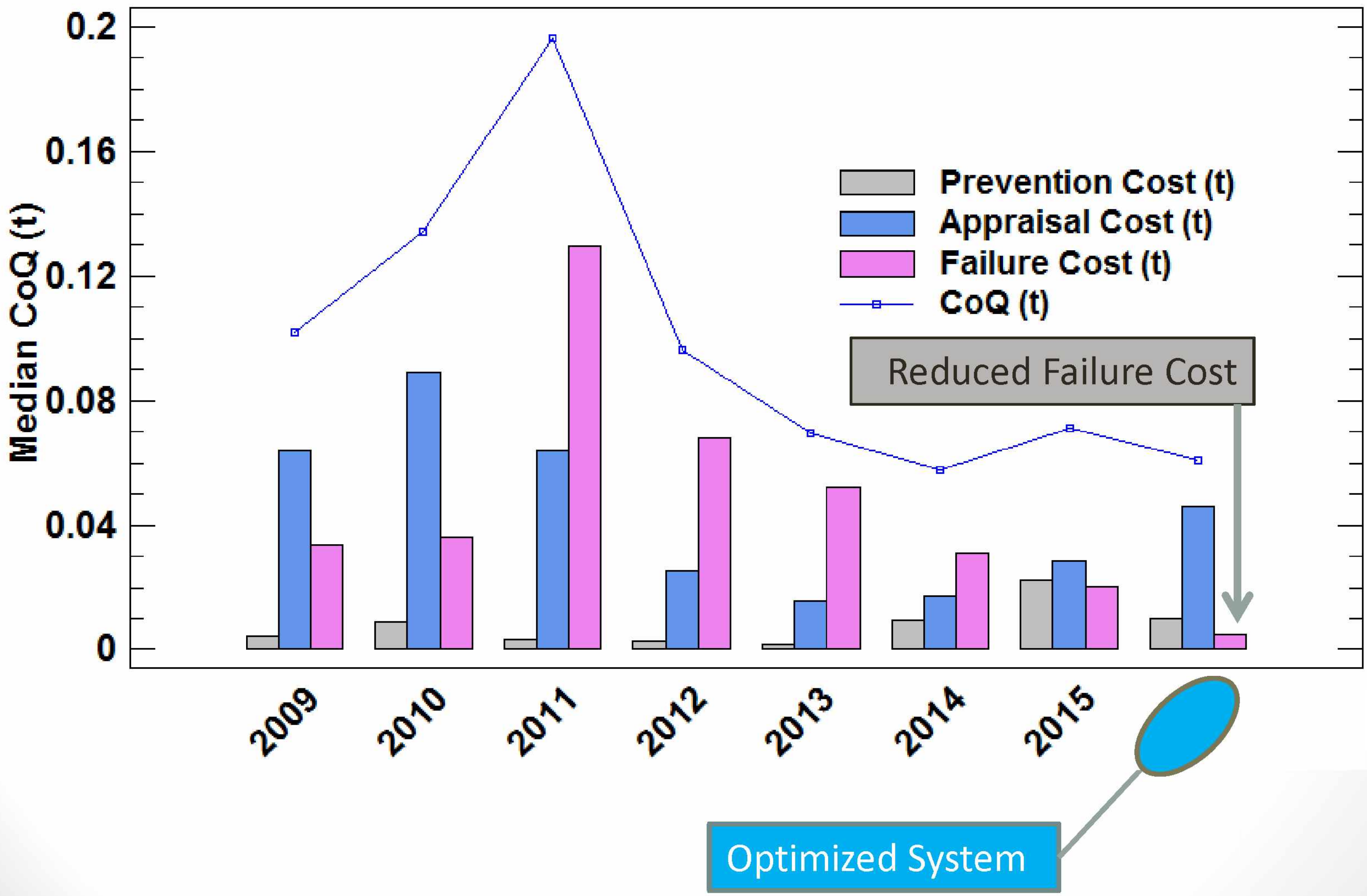
- Current Appraisal Costs:
  - Median Value = **2.7%**

RESULTS – SYSTEM OPTIMIZATION



RESULTS – SYSTEM OPTIMIZATION

FIRM'S COST OF QUALITY



CONCLUSIONS

1. Job size effect does not have an effect on CoQ at 95% Confidence. With the exception of Prevention Cost.

2. At 95% confidence we should reject the H_o that there is a statistically significant non-zero correlation exists between data sets. However, based on the modeling and regression analysis there is an obvious correlation.

3. The Firms Quality spending is not related to the Quality Budget at 95% Confidence.

4. The Firm's current CoQ does not appear to be optimized, based on the CoQ model.

MANAGERIAL ISSUES

- Project reviews decrease failure cost during construction.
  - Appraisal cost should be increased to 4.5% of overall budget.
- The Firms current QMS is not sufficient, consider ISO 9001 implementation.
  - Quality could be increased by 90.3%, in regards to failure cost.
- The firms current CoQ is 8.9%, the optimized system is 6.1%.
  - A goal should be established to reduce the overall CoQ.
  - Tracking must be implemented with QMS System.

FURTHER RESEARCH

- Future research on this subject could be to link the construction quality cost with the design.
  - Cloud Computing with BIM (Beach et al., 2013)
  - BIM Software linked with a project management software such as Spectrum®

- Marzouk et al (2012) suggests that the implementation of QMS lean principles could improve utilization of the design process by 40%.
  - Other quality initiatives could be looked at.

QUESTIONS?